CAIS STANDARD MANUAL

SYSTEM NO. 17
TUNNELS

CAS PROJECT
CAIS MANUAL

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MEMORANDUM FOR DTIC-OCP
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FROM: AL/EQ (STINFO)
139 Barnes Drive. Suite 2
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SUBJECT: Transmision of Technical Documents

1. As per telephone conversation with Andrew Poulis, EQ/TIC, the attached CAIS CTDS manuals are forwarded for accession, cataloging, and microconversions. Please forward the accession numbers to:

Andrew Poulis
AL/EQ/TIC
139 Barnes Drive. Suite 2
Tyndall AFB, FL 32403-5323

2. The Distribution statement should read as follows: Approved for Public Release: Distribution Unlimited.

3. If you have questions about these documents, please contact Andrew Poulis at DSN 523-6285.

Larry L. Testerman
LARRY L. TESTERMAN
Scientific and Technical
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Atchs: Manuals

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ABSTRACT

GENERAL ORGANIZATION

At this installation the list of facilities to be surveyed, including infrastructure, will be addressed on the basis of 32 unique systems that form the CAIS Engineering Deficiency Standards and Inspection Methods document. Each system deals with a specific technical aspect of the facility to be surveyed. Within each system a further breakdown is made to subsystems, each having a related list of components. Detailed observations of the listed defects are provided so as to allow the entry of observed quantification data. A DOD CAIS manual is provided for each of the 32 systems with an internal organization as outlined below:

INSPECTOR'S GUIDE

I. General
   - A. Level I Inspection Method Description
   - B. Level II Inspection Method Description
   - C. Level III Inspection Method Description

II. General Inspection
   - A. Process. This section describes the process of the inspection activity.
   - B. Location. This section describes the procedure for locating the inspection units in the facility or infrastructure on this installation.

III. Inspector Qualifications
   This section notes the minimum qualifications for the person or persons performing the survey.

IV. Inspector Unit
   This section describes how the IU (Inspection Unit) is determined for the particular component being surveyed.

V. Unit Costs
   This section notes the nature of repair costs for this system.

VI. Standard Safety Requirements
   This section lists safety procedures and equipment required to implement a safe environment for the conduct of this survey.

VII. Standard Tools
   This section lists a set of standard tools required for the general conduct of this survey.

VIII. Special Tools and Equipment Requirements
   This section refers to special tools or equipment requirements endemic to the nature of the system being surveyed.

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IX. Level II Inspection Method Keys
This section explains the use of keys as they relate to Level II Guide Sheets.

X. Level III Inspection Method Keys
This section explains the use of keys as they relate to Level III Guide Sheets.

XI. Replacement Cost
This section describes the nature and location of replacement cost data.

XII. Appendices
Appendix A. Provides a listing and definition of all abbreviations used both in the Standards and in the data base.

Appendix B. Provides a glossary of terms with their definitions as used in the Standard.

Appendix C. This section contains a listing of the average life cycle durations for each assembly* in the Standard.

* Assembly is a term describing the level at which replacement rather than repair occurs. This can be at the subsystem or component designation, depending on the system being surveyed.

SYSTEM TREE

The System Tree is a graphical representation of the Work Breakdown Structure, showing system, subsystem and component relationships for the Tunnels System.

INSPECTION METHODS

Description
Describes the nature of what is to be condition surveyed.

Special Tool and Equipment Requirements
Lists any special tools required for this specific subsystem.

Special Safety Requirements
This section outlines any special safety measures or equipment required for this specific subsystem so as to maintain a safe environment and process in the conduct of the condition survey.

Component List
All components to be surveyed under this subsystem are listed here.

Related Subsystems
All other subsystems that have a survey relationship to this subsystem are listed here to help coordinate a complete and thorough condition assessment survey.

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Standard Inspection Procedure

This statement indicates the various levels of survey effort required for this subsystem.

Components

The previously listed components of this subsystem are described with a survey procedure recommended on a component by component basis. For each component there is a listing of defects with each defect broken down into observations describing the nature and severity of the defective condition observed. The surveyor enters a quantification value for each defect/observation encountered in the field CAIS device (DCD) to record the result of his survey.

References

This page lists the reference sources from which the foregoing subsystem data was developed.

Guide Sheet Control Number

This section lists the key numbers that tie the written Level II and Level III guide sheets to specific components in this subsystem.

Level II and Level III Inspection Method Guide Sheets

This section contains the detailed descriptions of the Level II and III survey and inspection procedures for this subsystem.

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INSPECTOR'S GUIDE

I. GENERAL

A. Level I Inspection Method

The purpose of the Level I inspection is to detect observable defects in a tunnel and its portal structures. A tunnel is an active structure, subject to erosion, corrosion, and deterioration by wind, water, ice and temperature as well as the effects of vehicular and railway traffic. A well documented inspection will observe this deterioration and identify needed repairs that, if carried out, can prevent structural failure and provide full life cycle usage of the tunnel.

The Level I inspection for tunnels consists of an inspection of the readily accessible parts of the tunnel and portals as observed from the tunnel floor and entrances to the tunnel. The standard inspection is designed to be performed by a minimum of two inspectors, although additional personnel may be required to accompany the inspectors and handle portable lighting equipment if required.

The observations recorded by the field inspector during a Level I inspection are designed to create a historical data base for the continued useful life of the structure, to highlight particular items which require inspection by a qualified engineer experienced in the design and construction of tunnels, and to devise maintenance strategy.

B. Level II Inspection Method

A Level II inspection of tunnels is performed to obtain additional information or measurements concerning a defect observed during the course of the Level I inspection process or to inspect air supply and exhaust vent or drainage components which require the removal of a protective cover or necessitate entering an otherwise closed passage.

The Level II inspection is additional work performed by the inspection personnel during performance of the Level I inspection. Additional equipment will not be required to perform these inspections.

C. Level III Inspection Method

Level III inspections should be conducted by an engineer or team of engineers experienced in the design and construction of tunnels and should include a thorough systematic evaluation of the condition triggering its performance and an assessment of the safety and stability of the tunnel.

Level III inspections should be performed when triggered by conditions observed during a Level I or Level II inspection or on a regularly scheduled basis, whichever occurs first (see Facility Manager Guide). In addition, Level III inspections should be performed where the tunnels are less than 48 inches in diameter and require difficult access

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methods to be used; when work to be performed by others is required prior to gaining access to the tunnel; or where the tunnel or its components are of such size or function that remote inspection by portable television camera is required.

Depending on the assessment of the potential impact of observed conditions on the safety or stability of the tunnel, advanced test or inspection methods may be required as part of the Level III inspection to determine the cause and/or extent of an observed defect.

II. GENERAL INSPECTION

A. Process

The Level I inspection shall be carried out for each component listed in the Work Breakdown Structure (WBS) for a tunnel, where applicable. Potential defects have been identified in these standards along with relevant observations, allowing the inspector to prepare a record of observable conditions at the project site. The inspector will identify the defect, record the observation, and take measurements as necessary to record the quantity or extent of the defect. No attempt will be made to officially assess the safety of the tunnel during this inspection. The observation of certain defects may trigger a Level III inspection to be performed in order to confirm the severity of the observed defect and to assess the safety of the tunnel.

Prior to the start of a Level I inspection, the survey planners will obtain existing design or as-built drawings of the tunnel for use in preparing for the upcoming inspection. This preparatory work will include becoming familiarized with the layout, geometric configuration, and dimensions of the tunnel as well as calculating lengths, surface areas, cross sectional areas, volumes and the actual number of specific items to be surveyed and which are required to complete the "Total Quantity Inspected" prompt in the Field CAIS program.

B. Location

Level I and II inspections will be located by the inspector through a discrete entry into the Data Collection Device. The "IU" or component location will be derived from Facility-supplied segment numbering lists, maps or other I.D. numbering systems. For building associated "IU's" and components the Facility shall furnish plans annotated with room number schedules. In the case of non-room associated components, plans will be orientated with the top of each sheet being the north direction, so as to allow directional location and description. In the case where no maps or plans are available, the inspector shall enter a brief (65 character) description of location.

III. INSPECTOR QUALIFICATIONS

The personnel performing Standard Inspections of tunnels should have a minimum of 5 years experience in inspecting the physical conditions of tunnels. Inspectors will be specifically trained in the CAS system and its usage, and will be CAS certified.

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IV. INSPECTION UNIT (IU)

Inspection of an entire tunnel is generally performed at one time. The IU is normally defined as the entire component inspected: the unit of measure (UOM) for tunnel liners (metal panels, tile, concrete, masonry, or unlined tunnel) is SF (for the entire tunnel liner surface); UOM for the tunnel floor is LF; UOM for ventilation is SF; UOM for lighting is EA; and UOM for portals is SF.

The DS/IM for Tunnels has been prepared using the assumption that the IU for each of the above listed components is the entire inspected component. Components can not be arbitrarily divided up in the field by the field inspector to make it easier to identify location of a defect. Identification of defect locations is handled through data input in the "Comments" screen. Selection of arbitrary IU's will yield inconsistent results which are detrimental to the cost estimating processes in Site CAIS.

The "Total Quantity Inspected" prompt while recording quantities inspected in the Data Collection Device is not necessarily the same as the IU quantity. The "Total Quantity Inspected" density input should be equal to the total size or quantity of component or object being surveyed for an observation within a particular component. Therefore, the "Total Quantity Measured" within an IU will vary depending on the unit of measure for that particular observation as designated in the DS/IM.

V. UNIT COSTS

The unit costs that are applied to the quantities recorded for each observation are contained within the Site CAIS as component repair cost.

VI. STANDARD SAFETY REQUIREMENTS

Prior to inspection of the tunnel, the authority having jurisdiction such as the Facility Manager shall be notified to secure proper access, safety briefings, and personal safety items. See Master Safety Plan for additional requirements.

VII. STANDARD TOOLS

Employee Identification Card - to be worn or carried during all inspections
Handheld computer
Battery pack for handheld computer
100 ft tape measure
Folding Rule: 6 ft long (marked in inches or feet)
Flashlight

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VIII. SPECIAL TOOLS AND EQUIPMENT REQUIREMENTS

At the component level, there are no special tools and equipment are required for the Level I and Level II inspection of the associated components.

The use of a 35 mm camera is recommended during the Level I inspection to provide photo documentation of existing conditions of the dam structure and appurtenant works at the time of the inspection.

Level III guide sheets will address additional tools and equipment requirements that are specific to that particular method. Inspectors should review these sections in order to determine any special tool requirements for components they are to inspect.

IX. LEVEL II INSPECTION METHOD KEYS

Certain defect observations or the designated inspection of a certain component will trigger a Level II test or inspection. The Facility Manager will be able to identify defects where a Level II test or inspection is flagged. The Level II key at the observation level will refer to a specific guide sheet.

All Level II Guide Sheets are located at the end of each Subsystem section. A Guide Sheet Reference page precedes Level II and Level III Guide Sheets.

X. LEVEL III INSPECTION METHOD KEYS

Certain Level I and II Defect/Observations or scheduled occurrences will trigger a Level III inspection. The Level III key at the observation level will refer to a specific guide sheet. The Facility Manager will be able to identify deficiencies where a Level III inspection is flagged. These guide sheets, in many cases, will identify the Level III inspection and may refer the Facility Manager to a more sophisticated and costly test for consideration.

All Level III Guide Sheets are located at the end of each Subsystem section. A Guide Sheet Reference page precedes Level II and Level III Guide Sheets.

XI. REPLACEMENT COST

A replacement cost for each subsystem type will be contained within the cost estimating system in the Site CAIS. Remedial measure costs to correct observed defects will be estimated by the engineer(s) subsequent to the results of a Level III inspection.

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XII. APPENDICES

Appendix A - Abbreviations

A summary and definition of all abbreviations used in this system are contained in Appendix A which is located at the end of Tunnels.

Appendix B - Glossary

A glossary of terms and description of defects used in this system are contained in Appendix B which is located at the end of Tunnels.

Appendix C - Life Cycles

A listing of the average life cycle durations for each assembly* in the Standard.

Note - Facility Manager's Guide

The following are included in the Facility Manager's Guide:

A table showing the required manhours to perform the standard inspection for this facility listed by Cat Code (three digit).

A listing of all Level III inspections with their estimated cost and time to perform. This list will include frequency of inspection for time driven Level III's.

* Assembly is a term describing the level at which replacement rather than repair occurs. This can be at the subsystem or component designation, depending on the system being surveyed.

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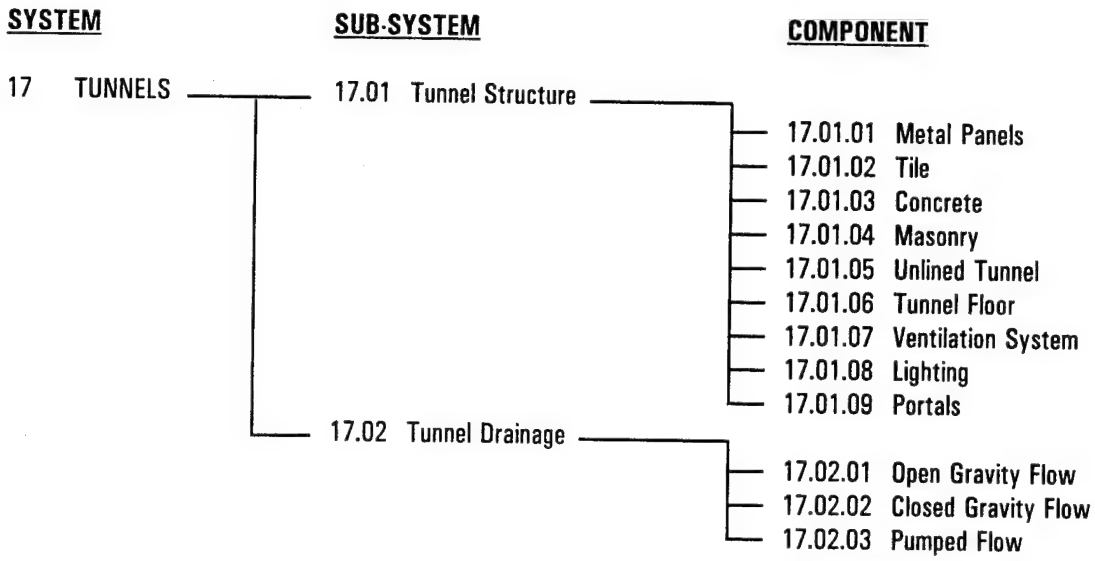
Figure 17-A. WORK BREAKDOWN STRUCTURE



17.01 TUNNEL STRUCTURE

DESCRIPTION

Tunnels are generally classified in one of four categories: vehicular traffic, railroad, pedestrian, or utility. Tunnels operated for transit, water and power provide services required on a continuing basis. These tunnels generally are built to last as long as they can be maintained in a practical and economically feasible manner. In contrast, tunnels constructed for mining or storage may be designed for a relatively short life. The principal difference between short and long service life is the degree of protection of the structural elements from corrosion or deterioration.

The tunnel structure generally consists of the floor, walls, roof and liner of the tunnel, the tunnel portals, and accessory components including ventilation and lighting. Depending on the design and use of the tunnel, observation within a tunnel may be limited to the existing condition of the tunnel liner and the tunnel floor. The tunnel liner may be homogeneous or vary between the walls and crown of the tunnel, depending on the design.

The primary components of tunnels are the tunnel liner (metal panel, tile, concrete, masonry, unlined), the tunnel floor (pavement, railroad track and ballast, rock floor), and the tunnel portals. Related components of tunnels which require inspection include the ventilation and lighting systems, where applicable.

It is not intended that inspection of the tunnel floor should be performed in lieu of a Level I inspection of the pavement or railroad track and ballast system where appropriate. These inspections must be performed by inspectors experienced in the design and operation of such structures.

SPECIAL TOOL AND EQUIPMENT REQUIREMENTS

No special tools are needed for the Level I and Level II inspection of the tunnels beyond the requirements listed in the Standard Tools Section, except for the following:

Rock Hammer
Hard hat with miners lamp and battery pack
Portable Lighting System, when applicable
Spray paint, keel, or flagging - to be used to mark stationing during inspection.
Portable Communication System, when applicable

SPECIAL SAFETY REQUIREMENTS

Level I inspection of any vehicular or railroad tunnel will include walking along the floor of the tunnel. Passing traffic may be a hazard to the inspectors. The inspection must be performed with the prior approval of the Facility Manager who will notify the authorities to provide safety measures and safe access. Inspection of railroad tunnels will require the use of flagmen posted outside the tunnel portals unless the Facility Manager or personnel under his jurisdiction has the authority to prohibit rail traffic during the time of inspection.

Level I inspection of utility tunnels (water, conduits, exclusive of sewer lines) greater than 48 inches in diameter will require removal of an access cover and descending into the tunnel.

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A minimum of two personnel will be required for these inspections (one in the tunnel, one at the top of the manhole structure). Continuous radio communication must be maintained between the inspector in the tunnel and any support personnel based outside the tunnel. Any person entering the tunnel must have safety equipment and follow safety measures as required by OSHA, the Master Safety Plan, and all other agencies having jurisdiction.

At the time of the Level I inspection, the inspection must be performed only after prior notification of the Facility Manager or person responsible for the tunnel, and the inspection personnel must check in with the above personnel upon completion of the inspection process.

Inspection of sewer tunnels shall only be performed as a Level III inspection by personnel qualified for inspection of sewer lines.

COMPONENT LIST

- 17.01.01 METAL PANELS
- 17.01.02 TILE
- 17.01.03 CONCRETE
- 17.01.04 MASONRY
- 17.01.05 UNLINED TUNNEL
- 17.01.06 TUNNEL FLOOR
- 17.01.07 VENTILATION
- 17.01.08 LIGHTING
- 17.01.09 PORTALS

RELATED SUBSYSTEMS

08.21	AIR DISTRIBUTION SYSTEMS
13.02	RETAINING WALLS
29.06	EXTERIOR LIGHTING SYSTEM
19.00	PAVEMENTS/IMPROVED SURFACES (all subsystems)
20.00	TRACKWORK (all subsystems)

STANDARD INSPECTION PROCEDURE

Prior to performing a Level I inspection, the inspector(s) should review existing records such as pre-construction investigation records, design criteria and analysis records, available construction records, and photographs taken during initial construction or subsequent site inspections, preceding inspection reports, notes, and photographs, and instrumentation records.

Review of the existing records and data calculated by the planners should result in the inspector becoming familiarized with the layout, geometric configuration, and dimensions of the tunnel as well as the historical record of the condition of the tunnel.

Once the field work commences and prior to the start of the actual recording of observed defect data, it will be necessary for the inspector to establish some measure of stationing along the tunnel alignment as necessary to establish a basis for locating observed defects.

17.01 TUNNEL STRUCTURE

Such stationing can match existing stationing shown on existing design or as-built drawings or can be established independently by the inspectors as long as the location of Station 0 + 00 is recorded. The direction of stationing measurement must also be given so that observation of potential defects on the "left wall" and "right wall" can be properly identified.

The Level I inspection of the tunnel structure generally involves walking the floor of the tunnel looking for deterioration, cracks, leakage, structural movement, or surface damage of the tunnel liner (or in the case of unlined tunnels, the roof and walls of the tunnel), and observing if weepholes in the tunnel liner are operating satisfactorily. The inspection also includes observation of existing conditions of the tunnel floor, a cursory view of the ventilation and lighting systems, and observation of conditions at the tunnel portals and front face slope overlying and adjacent to the portals.

For sunken tube tunnels, inspection of the air supply duct below the roadway and the exhaust air duct above the vehicular tunnel ceiling shall be performed as a Level II inspection. No additional personnel or equipment is necessary to inspect these ducts; however, gates or doors are required to be removed or opened and permission for access obtained prior to the performance of the inspection.

Inspection of the tunnel floors involves observations to determine if access through the tunnel is achievable for a vehicular or railroad tunnel and for signs of softening or heave of the tunnel floor in rock tunnels. Inspection for drainage problems along the tunnel floor are covered in Section 17.01.02.

17.01 TUNNEL STRUCTURE

STANDARD INSPECTION PROCEDURE (Continued)

Inspection of pavement conditions for vehicular tunnels should be performed in accordance with the written standards prepared for Pavements/Improved Surfaces. Similarly, inspection of the condition of railroad ties, ballast and rails should be performed by appropriate inspector personnel in accordance with the written standards prepared for Railroads.

Inspection of the lighting and ventilation systems as operating units should be carried out by appropriate inspection personnel in accordance with the standards prepared for Exhaust and Ventilation Systems and Exterior Lighting Systems. Inspection of these items during a Level I tunnel inspection is limited to observing that the lighting system is working and that the ventilation system (if applicable) is in-place. An exception to these limitations for inspection occurs when the ventilation system consists of a vertical chimney stack; in this case, the Level I tunnel inspector will observe the structure from both the top and bottom of the chimney structure and note any defects as presented in the standards for tunnel structure. Inspection of the tunnel portals includes observation for structural defects such as surface deterioration, cracking or displacement, as well as observation for slope instability problems in the front face slopes adjacent to and overlying the portals. Any applicable retaining walls along the approach slopes to the tunnel portals should be inspected in accordance with the written standards for Retaining Walls.

Photo documentation of existing conditions at the time of inspection is essential to creating a historical record of the condition of the tunnel over time. Photographs should be taken to record the overall (panorama view) condition of the tunnel as well as to record particular observed defects which are of concern. A record of photographs which have been taken can be input into the Data Collection Device by using the photo log option in the Comments screen. In addition, pertinent additional information which is observed during the Level I inspection, such as location or details of a particular observed defect, should be input into the Comments screen of the Data Collection Device.

Help screens have been developed and installed in the Field CAIS program to assist the Inspector during the Level I inspection for tunnels. Such help screens provide a brief summary of what is required for the inspection of a particular component, as well as a listing of potential defects to be looked for during the inspection. Full descriptions of potential defects are presented in Appendix B.

It is the intent of the standard inspection procedure to document the overall condition of the tunnel and to obtain an order of magnitude measure of the quantity of observed defects resulting in a budget projection of cost to repair or replace. The inspector should not focus on obtaining precise measurements. Due to the large scale of the components comprising a tunnel and to commonly difficult access conditions along a tunnel, it is often beneficial to estimate the areal or linear extent of a particular defect instead of spending an excessive amount of time trying to obtain an exact measure. It is acknowledged that estimating the unit of measure quantity is somewhat subjective, but doing so, when appropriate to conditions, will save considerable time during the inspection process. The comment screen should be used to indicate any backup data or assumptions made to indicate how the surveyor came up with a particular measure of observed defect if necessary.

17.01 TUNNEL STRUCTURE

COMPONENTS

◆ 17.01.01 METAL PANELS

Metal panel tunnel liners usually consist of cold-formed steel or aluminum panels filled with concrete. The panels generally vary in thickness from 2 to 4 inches, and are usually 6 to 13 feet long and range from 1.5 to 2.5 feet wide. Metal pan ceilings are widely used in highway tunnels. These ceilings are usually supported by hangers, string supports, and frames.

Potential defects which can be observed in metal panel tunnel liners include surface deterioration and damage, displacement or misalignment of the panels, or defects associated with the expansion joints.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Out-of-Alignment - Tunnel Roof**			
Observation:			
a. Bowing of metal panel less than 1".	SF		
*** {Severity L}			
b. Deflection of panel joints less than 1".	SF		
*** {Severity L}			
c. Bowing of metal panel greater than 1"	SF		
*** {Severity M}			
d. Deflection of panel joints greater than 1".	SF		
*** {Severity H}			
e. Shear displacement of panels greater than 1/2".	SF		
*** {Severity H}			
Defect:			
*** Out-of-Alignment - Left Wall**			
Observation:			
a. Bowing of metal panel less than 1".	SF		
*** {Severity L}			
b. Deflection of panel joints less than 1".	SF		
*** {Severity L}			
c. Bowing of metal panel greater than 1"	SF		
*** {Severity M}			
d. Deflection of panel joints greater than 1".	SF		
*** {Severity H}			
e. Shear displacement of panels greater than 1/2".	SF		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.01 METAL PANELS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Out-of-Alignment - Right Wall**			
Observation:			
a. Bowing of metal panel less than 1".	SF		
*** {Severity L}			
b. Deflection of panel joints less than 1".	SF		
*** {Severity L}			
c. Bowing of metal panel greater than 1"	SF		
*** {Severity M}			
d. Deflection of panel joints greater than 1".	SF		
*** {Severity H}			
e. Shear displacement of panels greater than 1/2".	SF		
*** {Severity H}			
Defect:			
*** Surface Deterioration of Metal Liner - Roof**			
Observation:			
a. Staining	SF		
*** {Severity L}			
b. Corrosion, rust	SF		
*** {Severity L}			
c. Plant growth	SF		
*** {Severity L}			
d. Small surface cracks	SF		
*** {Severity L}			
e. Crazing	SF		
*** {Severity M}			
Defect:			
*** Surface Deterioration of Metal Liner - Left Wall**			
Observation:			
a. Staining	SF		
*** {Severity L}			
b. Corrosion, rust	SF		
*** {Severity L}			
c. Plant growth	SF		
*** {Severity L}			
d. Small surface cracks	SF		
*** {Severity L}			
e. Crazing	SF		
*** {Severity M}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.01 METAL PANELS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Deterioration of Metal Liner - Right Wall**			
Observation:			
a. Staining	SF		
*** {Severity L}			
b. Corrosion, rust	SF		
*** {Severity L}			
c. Plant growth	SF		
*** {Severity L}			
d. Small surface cracks	SF		
*** {Severity L}			
e. Crazing	SF		
*** {Severity M}			
Defect:			
*** Surface Damage - Roof**			
Observation:			
a. Punctures, holes, tears less than 3" in diameter.	SF		
*** {Severity L}			
b. Punctures, holes, tears greater than 3" in diameter.	SF		
*** {Severity H}			
c. Impact damage, denting	SF		1
*** {Severity H}			
d. Completely damaged or missing sections	SF		
*** {Severity H}			
Defect:			
*** Surface Damage - Left Wall**			
Observation:			
a. Punctures, holes, tears less than 3" in diameter.	SF		
*** {Severity L}			
b. Punctures, holes, tears greater than 3" in diameter.	SF		
*** {Severity H}			
c. Impact damage, denting	SF		1
*** {Severity H }			
d. Completely damaged or missing sections	SF		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.01 METAL PANELS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Damage - Right Wall**			
Observation:			
a. Punctures, holes, tears less than 3" in diameter.	SF		
*** {Severity L}			
b. Punctures, holes, tears greater than 3" in diameter.	SF		
*** {Severity H}			
c. Impact damage, denting	SF		1
*** {Severity H}			
d. Completely damaged or missing sections	SF		
*** {Severity H}			
Defect:			
*** Expansion Joints - Roof**			
Observation:			
a. Joint separation less than 1/4".	LF		
*** {Severity L}			
b. Joint separation between 1/4" and 1".	LF		
*** {Severity M}			
c. Joint separation greater than 1".	LF		1
*** {Severity H}			
Defect:			
*** Expansion Joints - Left Wall**			
Observation:			
a. Joint separation less than 1/4".	LF		
*** {Severity L}			
b. Joint separation between 1/4" and 1".	LF		
*** {Severity M}			
c. Joint separation greater than 1".	LF		1
*** {Severity H}			
Defect:			
*** Expansion Joints - Right Wall**			
Observation:			
a. Joint separation less than 1/4".	LF		
*** {Severity L}			
b. Joint separation between 1/4" and 1".	LF		
*** {Severity M}			
c. Joint separation greater than 1".	LF		1
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.02 TILE

Ceramic tile is a type of veneered finish which is directly applied to the structural tunnel lining. The tile is generally attached to the surface of the tunnel liner through the use of an adhesive. The surface of the tile must be smooth to reduce friction loss of air flow through the tunnel and to avoid requirements to include a ventilation system. Tile liners are commonly used in highway tunnels.

Potential defects which can be observed in tile liners include weathering characteristics such as changes in color, texture, and strength, or surface damage including spalling, loose tiles, or damaged or missing tiles.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Weathering - Roof**			
Observation:			
a. Color change, discoloration.	SF		
*** {Severity L}			
b. Textural change, tile exhibits rough worn surface.	SF		
*** {Severity L}			
c. Noticeable loss of strength of tile liner.	SF		
*** {Severity M}			
Defect:			
*** Weathering - Left Wall**			
Observation:			
a. Color change, discoloration.	SF		
*** {Severity L}			
b. Textural change, tile exhibits rough worn surface.	SF		
*** {Severity L}			
c. Noticeable loss of strength of tile liner.	SF		
*** {Severity M}			
Defect:			
*** Weathering - Right Wall**			
Observation:			
a. Color change, discoloration.	SF		
*** {Severity L}			
b. Textural change, tile exhibits rough worn surface.	SF		
*** {Severity L}			
c. Noticeable loss of strength of tile liner.	SF		
*** {Severity M}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.02 TILE (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Damage - Roof**			
Observation:			
a. Spalling.	SF		
*** {Severity L}			
b. Loose tile.	SF		
*** {Severity M}			
c. Damaged or missing tile.	SF		
*** {Severity H}			
Defect:			
*** Surface Damage - Left Wall**			
Observation:			
a. Spalling.	SF		
*** {Severity L}			
b. Loose tile.	SF		
*** {Severity M}			
c. Damaged or missing tile.	SF		
*** {Severity H}			
Defect:			
*** Surface Damage - Right Wall**			
Observation:			
a. Spalling.	SF		
*** {Severity L}			
b. Loose tile.	SF		
*** {Severity M}			
c. Damaged or missing tile.	SF		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.03 CONCRETE

A cast-in-place concrete tunnel liner generally consists of a reinforced concrete ceiling slab at least 4 to 6 inches thick which spans transversely between the tunnel walls and supports. Composite concrete and structural beams or steel stringers provide the main support. Interior spans vary. Details of the concrete tunnel liner can be found in the design or construction drawings.

Potential defects which can be observed in a concrete tunnel liner include movement of the liner; cracking of the foundation walls; surface weathering or damage; deterioration of any exposed steel reinforcing; bowing or deflection of the liner; or lack of expansion or control joints resulting in localized cracking of the concrete.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Lining Movement - Roof**			
Observation:			
a. Settlement of roof less than 1". *** {Severity L}	SF		
b. Settlement of roof greater than 1". *** {Severity M}	SF		2
c. Lateral movement or separation. *** {Severity H}	SF		2
Defect:			
*** Lining Movement - Left Wall**			
Observation:			
a. Settlement of wall less than 1". *** {Severity L}	SF		
b. Settlement of wall greater than 1". *** {Severity M}	SF		2
c. Lateral movement or separation. *** {Severity H}	SF		2
Defect:			
*** Lining Movement - Right Wall**			
Observation:			
a. Settlement of wall less than 1". *** {Severity L}	SF		
b. Settlement of wall greater than 1". *** {Severity M}	SF		2
c. Lateral movement or separation. *** {Severity H}	SF		2

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.03 CONCRETE (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Cracking - Roof**			
Observation:			
a. Cracks less than 1/4" open.	SF		
*** {Severity L}			
b. Cracks 1/4" to 1" open.	SF		
*** {Severity M}			
c. Cracks greater than 1" open.	LF		2
*** {Severity H}			
Defect:			
*** Cracking - Left Wall**			
Observation:			
a. Cracks less than 1/4" open.	SF		
*** {Severity L}			
b. Cracks 1/4" to 1" open.	SF		
*** {Severity M}			
c. Cracks greater than 1" open.	LF		2
*** {Severity H}			
Defect:			
*** Cracking - Right Wall**			
Observation:			
a. Cracks less than 1/4" open.	SF		
*** {Severity L}			
b. Cracks 1/4" to 1" open.	SF		
*** {Severity M}			
c. Cracks greater than 1" open.	LF		2
*** {Severity H}			
Defect:			
*** Surface Weathering - Roof**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.03 CONCRETE (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Surface Weathering - Left Wall**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			
Defect:			
*** Surface Weathering - Right Wall**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			
Defect:			
*** Surface Damage - Roof**			
Observation:			
a. Spalling, chipped concrete.	SF		
*** {Severity L}			
b. Settlement in concrete.	SF		
*** {Severity L}			
c. Alkali-aggregate expansion.	SF		
*** {Severity L}			
d. Cavitation.	SF		
*** {Severity L}			
e. Crazing.	SF		
*** {Severity L}			
f. Concrete section exhibiting holes.	SF		
*** {Severity L}			
g. Form Scabbing.	SF		
*** {Severity L}			
h. Delamination.	SF		
*** {Severity L}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.03 CONCRETE (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Surface Damage - Left Wall**			
Observation:			
a. Spalling, chipped concrete.	SF		
*** {Severity L}			
b. Settlement in concrete.	SF		
*** {Severity L}			
c. Alkali-aggregate expansion.	SF		
*** {Severity L}			
d. Cavitation.	SF		
*** {Severity L}			
e. Crazing.	SF		
*** {Severity L}			
f. Concrete section exhibiting holes.	SF		
*** {Severity L}			
g. Form Scabbing.	SF		
*** {Severity L}			
h. Delamination.	SF		
*** {Severity L}			
Defect:			
*** Surface Damage - Right Wall**			
Observation:			
a. Spalling, chipped concrete.	SF		
*** {Severity L}			
b. Settlement in concrete.	SF		
*** {Severity L}			
c. Alkali-aggregate expansion.	SF		
*** {Severity L}			
d. Cavitation.	SF		
*** {Severity L}			
e. Crazing.	SF		
*** {Severity L}			
f. Concrete section exhibiting holes.	SF		
*** {Severity L}			
g. Form Scabbing.	SF		
*** {Severity L}			
h. Delamination.	SF		
*** {Severity L}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.03 CONCRETE (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Steel Deterioration - Roof**			
Observation:			
a. Exposed steel reinforcing.	SF		
*** {Severity L}			
b. Corrosion of steel reinforcing.	SF		
*** {Severity M}			
c. Broken, damaged, loose, corroded, or missing anchorages or fasteners	EA		
*** {Severity H}			
Defect:			
*** Steel Deterioration - Left Wall**			
Observation:			
a. Exposed steel reinforcing.	SF		
*** {Severity L}			
b. Corrosion of steel reinforcing.	SF		
*** {Severity M}			
c. Broken, damaged, loose, corroded, or missing anchorages or fasteners	EA		
*** {Severity H}			
Defect:			
*** Steel Deterioration - Right Wall**			
Observation:			
a. Exposed steel reinforcing.	SF		
*** {Severity L}			
b. Corrosion of steel reinforcing.	SF		
*** {Severity M}			
c. Broken, damaged, loose, corroded, or missing anchorages or fasteners	EA		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.03 CONCRETE (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Out-of-Alignment - Tunnel Roof**			
Observation:			
a. Bowing of concrete liner less than 1".	SF		
*** {Severity L}			
b. Deflection of concrete liner less than 1".	SF		
*** {Severity L}			
c. Bowing of concrete liner greater than 1".	SF		
*** {Severity M}			
d. Deflection of concrete liner greater than 1".	SF		
*** {Severity H}			
e. Shear displacement of liner greater than 1/2".	SF		2
*** {Severity H}			
Defect:			
*** Out-of-Alignment - Left Wall**			
Observation:			
a. Bowing of concrete liner less than 1".	SF		
*** {Severity L}			
b. Deflection of concrete liner less than 1".	SF		
*** {Severity L}			
c. Bowing of concrete liner greater than 1"	SF		
*** {Severity M}			
d. Deflection of concrete liner greater than 1".	SF		
*** {Severity H}			
e. Shear displacement of liner greater than 1/2".	SF		2
*** {Severity H}			
Defect:			
*** Out-of-Alignment - Right Wall**			
Observation:			
a. Bowing of concrete liner less than 1".	SF		
*** {Severity L}			
b. Deflection of concrete liner less than 1".	SF		
*** {Severity L}			
c. Bowing of concrete liner greater than 1".	SF		
*** {Severity M}			
d. Deflection of concrete liner greater than 1".	SF		
*** {Severity H}			
e. Shear displacement of liner greater than 1/2".	SF		2
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.03 CONCRETE (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Construction Joints - Tunnel Roof**			
Observation:			
a. Joint separation less than 1/4". *** {Severity L}	LF		
b. Joint separation between 1/4" and 1". *** {Severity M}	LF		
c. Joint separation greater than 1". *** {Severity H}	LF		2
Defect:			
*** Construction Joints - Left Wall**			
Observation:			
a. Joint separation less than 1/4". *** {Severity L}	LF		
b. Joint separation between 1/4" and 1". *** {Severity M}	LF		
c. Joint separation greater than 1". *** {Severity H}	LF		2
Defect:			
*** Construction Joints - Right Wall**			
Observation:			
a. Joint separation less than 1/4". *** {Severity L}	LF		
b. Joint separation between 1/4" and 1". *** {Severity M}	LF		
c. Joint separation greater than 1". *** {Severity H}	LF		2

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.04 MASONRY

Brick/masonry arch tunnels are generally constructed by cut-and-cover techniques. These tunnels consist of steel framing spaced approximately 8 feet on-center for walls and at 4 feet centers for roof sections. The spaces between the steel framing are filled with brick in an arch shape. Some tunnels with brick liners do not have steel framing. The brick and ceiling vaults are usually 24 inches thick and covered on the exterior with pitch for waterproofing purposes. Brick/masonry arch tunnels were used extensively in early transit and railway systems. Details of the masonry liner can be obtained from the design or construction drawings.

Potential defects which can be observed in a brick/masonry tunnel include a change in shape of the tunnel liner (out-of-alignment); deterioration or damage of the masonry surface; deterioration of any associated steel reinforcement; or blockage of existing weepholes.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Out-of-Alignment - Tunnel Roof**			
Observation:			
a. Bowing of masonry liner less than 1". *** {Severity L}	SF		
b. Deflection of masonry liner less than 1". *** {Severity L}	SF		
c. Bowing of masonry liner greater than 1". *** {Severity M}	SF		
d. Deflection of masonry liner greater than 1". *** {Severity H}	SF		3
e. Shear displacement of liner greater than 1/2". *** {Severity H}	SF		3
Defect:			
*** Out-of-Alignment - Left Wall**			
Observation:			
a. Bowing of masonry liner less than 1". *** {Severity L}	SF		
b. Deflection of masonry liner less than 1". *** {Severity L}	SF		
c. Bowing of masonry liner greater than 1". *** {Severity M}	SF		
d. Deflection of masonry liner greater than 1". *** {Severity H}	SF		3
e. Shear displacement of liner greater than 1/2". *** {Severity H}	SF		3

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.04 MASONRY (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Out-of-Alignment - Right Wall**			
Observation:			
a. Bowing of masonry liner less than 1".	SF		
*** {Severity L}			
b. Deflection of masonry liner less than 1".	SF		
*** {Severity L}			
c. Bowing of masonry liner greater than 1".	SF		
*** {Severity M}			
d. Deflection of masonry liner greater than 1".	SF		3
*** {Severity H}			
e. Shear displacement of liner greater than 1/2".	SF		3
*** {Severity H}			
Defect:			
*** Surface Deterioration - Tunnel Roof**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			
d. Crazing.	SF		
*** {Severity L}			
Defect:			
*** Surface Deterioration - Left Wall**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			
d. Crazing.	SF		
*** {Severity L}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.04 MASONRY (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Deterioration - Right Wall**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			
d. Crazing.	SF		
*** {Severity L}			
Defect:			
*** Surface Damage - Tunnel Roof**			
Observation:			
a. Spalling, chipped masonry.	SF		
*** {Severity L}			
b. Missing joint mortar.	SF		
*** {Severity M}			
c. Damaged or missing rows of masonry.	SF		
*** {Severity M}			
d. Broken, damaged, loose, corroded or missing anchorage or fasteners.	EA		
*** {Severity H}			
Defect:			
*** Surface Damage - Left Wall**			
Observation:			
a. Spalling, chipped masonry.	SF		
*** {Severity L}			
b. Missing joint mortar.	SF		
*** {Severity M}			
c. Damaged or missing rows of masonry.	SF		
*** {Severity M}			
d. Broken, damaged, loose, corroded or missing anchorage or fasteners.	EA		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.04 MASONRY (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Damage - Right Wall**			
Observation:			
a. Spalling, chipped masonry.	SF		
*** {Severity L}			
b. Missing joint mortar.	SF		
*** {Severity M}			
c. Damaged or missing rows of masonry.	SF		
*** {Severity M}			
d. Broken, damaged, loose, corroded or missing anchorage or fasteners.	EA		
*** {Severity H}			
Defect:			
*** Steel Deterioration - Tunnel Roof**			
Observation:			
a. Exposed rusted or corroded steel reinforcing or framing.	SF		
*** {Severity M}			
Defect:			
*** Steel Deterioration - Left Wall**			
Observation:			
a. Exposed rusted or corroded steel reinforcing or framing.	SF		
*** {Severity M}			
Defect:			
*** Steel Deterioration - Right Wall**			
Observation:			
a. Exposed rusted or corroded steel reinforcing or framing.	SF		
*** {Severity M}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.04 MASONRY (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Weepholes - Left Wall**			
Observation:			
a. Blocked or clogged weepholes.	EA		
*** {Severity M}			
Defect:			
*** Weepholes - Right Wall**			
Observation:			
a. Blocked or clogged weepholes.	EA		
*** {Severity M}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.05 UNLINED TUNNEL

Depending on the type, hardness, physical properties and fracture characteristics of the rock mass, tunnels can be constructed without the use of a permanent inner liner. For purposes of this inspection standard, unlined tunnels will include tunnels which do not require any tunnel liner measures, or cases where the rock is stabilized only through the use of rock reinforcement (rock bolts, dowels, anchors, etc.) and/or the use of shotcrete.

Potential defects which can be observed in unlined tunnels include weathering or deterioration of the rock surface; seepage into the tunnel; instability of sections of the tunnel roof or walls; or deterioration of the shotcrete layer.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Weathering/Surface Deterioration - Tunnel Roof**			
Observation:			
a. Tunnel roof rock is slightly weathered.	SF		
*** {Severity L}			
b. Staining.	SF		
*** {Severity L}			
c. Friable rock surface.	SF		
*** {Severity L}			
d. Tunnel roof rock is moderately weathered.	SF		
*** {Severity M}			
e. Tunnel roof rock is severely weathered.	SF		4
*** {Severity H}			
f. Strength loss of rock.	SF		4
*** {Severity H}			

Defect:

*** Weathering/Surface Deterioration - Left Wall**			
Observation:			
a. Tunnel wall rock is slightly weathered.	SF		
*** {Severity L}			
b. Staining.	SF		
*** {Severity L}			
c. Friable rock surface.	SF		
*** {Severity L}			
d. Tunnel wall rock is moderately weathered.	SF		
*** {Severity M}			
e. Tunnel wall rock is severely weathered.	SF		4
*** {Severity H}			
f. Strength loss of rock.	SF		4
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.05 UNLINED TUNNEL (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Weathering/Surface Deterioration - Right Wall**			
Observation:			
a. Tunnel wall rock is slightly weathered.	SF		
*** {Severity L}			
b. Staining.	SF		
*** {Severity L}			
c. Friable rock surface.	SF		
*** {Severity L}			
d. Tunnel wall rock is moderately weathered.	SF		
*** {Severity M}			
e. Tunnel wall rock is severely weathered.	SF		4
*** {Severity H}			
f. Strength loss of rock.	SF		4
*** {Severity H}			

Defect:

*** Seepage - Tunnel Roof**

Observation:

a. Dampness or wet roof rock. SF
*** {Severity L}

b. Water dripping from roof rock, not associated with rock discontinuities. SF
*** {Severity M}

c. Water dripping from roof rock, associated with rock discontinuities. SF
*** {Severity M}

d. Water flowing (greater than 1 gpm) into the tunnel through the roof, not associated with rock discontinuities. SF 4
*** {Severity H}

e. Water flowing (greater than 1 gpm) from the tunnel roof, associated with rock discontinuities. SF 4
*** {Severity H}

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.05 UNLINED TUNNEL (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Seepage - Left Wall**			
Observation:			
a. Dampness or wet wall rock.	SF		
*** {Severity L}			
b. Water dripping from wall rock, not associated with rock discontinuities.	SF		
*** {Severity M}			
c. Water dripping from wall rock, associated with rock discontinuities.	SF		
*** {Severity M}			
d. Water flowing (greater than 1 gpm) into the tunnel through the wall, not associated with rock discontinuities.	SF		4
*** {Severity H}			
e. Water flowing (greater than 1 gpm) from the tunnel wall, associated with rock discontinuities.	SF		4
*** {Severity H}			
Defect:			
*** Seepage - Right Wall**			
Observation:			
a. Dampness or wet wall rock.	SF		
*** {Severity L}			
b. Water dripping from wall rock, not associated with rock discontinuities.	SF		
*** {Severity M}			
c. Water dripping from wall rock, associated with rock discontinuities.	SF		
*** {Severity M}			
d. Water flowing (greater than 1 gpm) into the tunnel through the wall, not associated with rock discontinuities.	SF		4
*** {Severity H}			
e. Water flowing (greater than 1 gpm) from the tunnel wall, associated with rock discontinuities.	SF		4
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.05 UNLINED TUNNEL (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Rock Instability - Tunnel Roof**			
Observation:			
a. Open joints or rock discontinuities in tunnel roof.	SF		
*** {Severity M}			
b. Loose rock reinforcement measures (i.e. rockbolts, rock dowels, anchors, etc.)	EA		
*** {Severity M}			
c. Cracks greater than 1/2" open in roof rock, or obvious sagging of roof rock.	SF		4
*** {Severity H}			
d. Rock fall or slabs accumulated on tunnel floor, obvious indications that rockfall originated from roof.	SF		4
*** {Severity H}			
e. Rock bursts.	SF		4
*** {Severity H}			

Defect:

*** Rock Instability - Left Wall**			
Observation:			
a. Open joints or rock discontinuities in tunnel wall.	SF		
*** {Severity M}			
b. Loose rock reinforcement measures (i.e. rockbolts, rock dowels, anchors, etc.)	EA		
*** {Severity M}			
c. Cracks greater than 1/2" open in tunnel wall rock, not associated with rock discontinuities.	SF		4
*** {Severity H}			
d. Rock fall or slabs accumulated on tunnel floor, obvious indications that rockfall originated from wall of tunnel.	SF		4
*** {Severity H}			
e. Rock bursts.	SF		4
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.05 UNLINED TUNNEL (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Rock Instability - Right Wall**			
Observation:			
a. Open joints or rock discontinuities in tunnel wall.	SF		
*** {Severity M}			
b. Loose rock reinforcement measures (i.e. rockbolts, rock dowels, anchors, etc.)	EA		
*** {Severity M}			
c. Cracks greater than 1/2" open in tunnel wall rock, not associated with rock discontinuities.	SF		4
*** {Severity H}			
d. Rock fall or slabs accumulated on tunnel floor, obvious indications that rockfall originated from wall of tunnel.	SF		4
*** {Severity H}			
e. Rock bursts.	SF		4
*** {Severity H}			
Defect:			
*** Shotcrete/Gunite Liner - Tunnel Roof**			
Observation:			
a. Shotcrete/gunite liner exhibits staining or discoloration.	SF		
*** {Severity L}			
b. Shotcrete/gunite liner exhibits multiple cracks in an isolated area.	SF		
*** {Severity L}			
c. Shotcrete/gunite liner exhibits loss of bonding with underlying rock.	SF		
*** {Severity M}			
d. Shotcrete/gunite liner sections missing from tunnel roof.	SF		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.05 UNLINED TUNNEL (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Shotcrete/Gunite Liner - Left Wall**			
Observation:			
a. Shotcrete/gunite liner exhibits staining or discoloration.	SF		
*** {Severity L}			
b. Shotcrete/gunite liner exhibits multiple cracks in an isolated area.	SF		
*** {Severity L}			
c. Shotcrete/gunite liner exhibits loss of bonding with underlying rock.	SF		
*** {Severity M}			
d. Shotcrete/gunite liner sections missing from tunnel wall.	SF		
*** {Severity H}			

Defect:

*** Shotcrete/Gunite Liner - Right Wall**			
Observation:			
a. Shotcrete/gunite liner exhibits staining or discoloration.	SF		
*** {Severity L}			
b. Shotcrete/gunite liner exhibits multiple cracks in an isolated area.	SF		
*** {Severity L}			
c. Shotcrete/gunite liner exhibits loss of bonding with underlying rock.	SF		
*** {Severity M}			
d. Shotcrete/gunite liner sections missing from tunnel wall.	SF		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.06 TUNNEL FLOOR

Composition of the tunnel floor will vary depending on the usage of the tunnel: railroad tunnels have ballast, railroad ties, and rails; vehicular tunnels have some type of pavement structure; utility tunnels may have the same composition bottom as the walls of the tunnel or a concrete slab; and storage tunnels may have a floor consisting of a concrete slab, base course material, or the underlying bedrock.

The purpose of the Level I inspection of the tunnel floor is to observe if the tunnel floor is clear for vehicular or railroad traffic, where applicable, or to observe any softening condition of the tunnel floor which may result in instability of the tunnel walls and roof. Any temporary closures or blockages due to maintenance or construction activities should be noted. Inspection of the paved tunnel floor or railroad track and ballast system, if applicable, should be performed by appropriate personnel in accordance with the written standards for Pavements/Improved Surfaces or Trackways.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Roadway Clearance - Vehicular Tunnel**			
Observation:			
a. Roadway temporarily blocked due to maintenance or construction activity.	LF		
*** {Severity L}			
b. Longterm blockage due to slope instability near the tunnel portals or deteriorated pavement.	LF		5
*** {Severity H}			
Defect:			
*** Rail Clearance - Railroad Tunnel**			
Observation:			
a. Railroad temporarily blocked due to maintenance or construction activity.	LF		
*** {Severity L}			
b. Longterm blockage due to deteriorated ballast and rail system.	LF		5
*** {Severity H}			
c. Longterm blockage due to slope instability near the tunnel portals.	LF		6
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.06 TUNNEL FLOOR (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Softening/Heave of Unlined Tunnel Floor**			
Observation:			
a. Standing water pooled along tunnel floor. *** {Severity L}	SF		
b. Rock floor soft to walk on. *** {Severity M}	SF		6
c. Individual footings or columns of center walls appear to have settled. *** {Severity H}	LF		6
d. Floor heave. *** {Severity H}	SF		6

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.07 VENTILATION SYSTEM

All vehicular tunnels require ventilation. Natural ventilation, combining the effects of meteorological conditions with moving traffic, is adequate for relatively short tunnels and for railroad tunnels. Some naturally vented tunnels include an intermediate shaft or chimney in addition to the ventilation at the portals. For longer tunnels, mechanical ventilation systems designed for the length of tunnel and expected traffic volume are used.

Sunken tube tunnels include air supply ducts and air exhaust ducts located below and above the vehicular tunnel, respectively, as well as extensive mechanical ventilation systems. Due to required access through ventilation buildings, inspection of these ducts are classified as a Level II inspection. Potential defects and observations for air supply and exhaust ducts are presented in these inspection standards and a Level II guide sheet is prepared to address required inspection procedures.

The purpose of the Level I inspection of the tunnel structure is to note if the tunnel is naturally or mechanically ventilated. If the tunnel is naturally ventilated, inspection is limited to observation of conditions of the intermediate shaft or chimney, if applicable, from the tunnel floor and from the top of the chimney if accessible. Inspection of a mechanical ventilation system should be performed by appropriate personnel in accordance with the written standards for Ventilation Systems.

Potential defects which can be observed in a Level I inspection of a ventilation shaft include surface deterioration, cracking of the structure walls, or blockage of the shaft from further ventilation.

Defect:	UOM	LEVEL II KEY	LEVEL I KEY
*** Blockage of Ventilation Shaft**			
Observation:			
a. Ventilation shaft less than 25% blocked by debris.	SF		
*** {Severity L}			
b. Ventilation shaft 25% to 75% blocked by debris.	SF		
*** {Severity M}			
c. Ventilation shaft greater than 75% blocked by debris.	SF		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.07 VENTILATION SYSTEM (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Damage (Masonry) - Ventilation Shaft**			
Observation:			
a. Spalling, chipped masonry.	SF		
*** {Severity L}			
b. Missing joint mortar.	SF		
*** {Severity M}			
c. Damaged or missing rows of masonry.	SF		
*** {Severity M}			
d. Broken, damaged, loose, corroded or missing anchorage or fasteners.	EA		
*** {Severity H}			
Defect:			
*** Surface Damage (Concrete) - Ventilation Shaft**			
Observation:			
a. Spalling, chipped concrete.	SF		
*** {Severity L}			
b. Cavitation.	SF		
*** {Severity L}			
e. Crazing.	SF		
*** {Severity L}			
Defect:			
*** Cracking - Ventilation Shaft**			
Observation:			
a. Cracks less than 1/4" open.	SF		
*** {Severity L}			
b. Cracks 1/4" to 1" open.	SF		
*** {Severity M}			
c. Cracks greater than 1" open.	LF		7
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.07 VENTILATION SYSTEM (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Damage (Concrete Floor) - Air Supply Duct, Sunken Tube Tunnel**			
Observation:			
a. Spalling, chipped concrete. *** {Severity L}	SF	1	
b. Cavitation. *** {Severity L}	SF	1	
c. Exposed steel reinforcing. *** {Severity H}	SF	1	
Defect:			
*** Cracking (Concrete Floor) - Air Supply Duct, Sunken Tube Tunnel**			
Observation:			
a. Cracks less than 1/16" open. *** {Severity L}	SF	1	
b. Cracks 1/16" to 1/8" open. *** {Severity M}	SF	1	
c. Cracks greater than 1/8" open. *** {Severity H}	SF	1	7
Defect:			
*** Seepage (Concrete Floor) - Air Supply Duct, Sunken Tube Tunnel**			
Observation:			
a. Damp concrete floor. *** {Severity L}	SF	1	
b. Wet concrete floor. *** {Severity M}	SF	1	
c. Seepage through floor greater than 1/2 gpm. *** {Severity H}	SF	1	7

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.07 VENTILATION SYSTEM (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Longitudinal Cracking of Underneath Side of Vehicular Slab - Air Supply Duct, Sunken Tube Tunnel**			
Observation:			
a. Hairline crack less than 1/16" open. *** {Severity L}	SF	1	
b. Open crack between 1/16" and 1/8" wide. *** {Severity M}	SF	1	
c. Open crack greater than 1/8" wide. *** {Severity H}	SF	1	7
Defect:			
*** Latitudinal Cracking of Underneath Side of Vehicular Slab - Air Supply Duct, Sunken Tube Tunnel**			
Observation:			
a. Hairline crack less than 1/16" open. *** {Severity L}	SF	1	
b. Open crack between 1/16" and 1/8" wide. *** {Severity M}	SF	1	
c. Open crack greater than 1/8" wide. *** {Severity H}	SF	1	7
Defect:			
*** Structural Beam Deterioration (Roof) - Air Supply Duct, Sunken Tube Tunnel**			
Observation:			
a. Surface rusting, less than 25% of beam. *** {Severity L}	SF	1	
b. Rusting or pitted surface, less than 50% of beam. *** {Severity M}	SF	1	
c. Rusting or pitted surface greater than 50% of beam, or voids or open seams in beam. *** {Severity H}	SF	1	7

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.07 VENTILATION SYSTEM (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Seepage (Concrete Roof) - Air Exhaust Duct, Sunken Tube Tunnel**			
Observation:			
a. Damp concrete roof.	SF	1	
*** {Severity L}			
b. Wet concrete roof.	SF	1	
*** {Severity M}			
c. Seepage through roof greater than 1/2 gpm.	SF	1	7
*** {Severity H}			
Defect:			
*** Surface Damage (Concrete Floor) - Air Exhaust Duct, Sunken Tube Tunnel**			
Observation:			
a. Spalling, chipped concrete.	SF	1	
*** {Severity L}			
b. Cavitation.	SF	1	
*** {Severity L}			
c. Exposed steel reinforcing.	SF	1	
*** {Severity H}			
Defect:			
*** Cracking of Concrete Floor Slab - Air Exhaust Duct, Sunken Tube Tunnel**			
Observation:			
a. Hairline crack less than 1/16" open.	SF	1	
*** {Severity L}			
b. Open crack between 1/16" and 1/8" wide.	SF	1	
*** {Severity M}			
c. Open crack greater than 1/8" wide.	SF	1	7
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.07 VENTILATION SYSTEM (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Surface Damage (Concrete Roof) - Air Exhaust Duct, Sunken Tube Tunnel**			
Observation:			
a. Spalling, chipped concrete.	SF	1	
*** {Severity L}			
b. Cavitation.	SF	1	
*** {Severity L}			
c. Exposed steel reinforcing.	SF	1	
*** {Severity H}			
Defect:			
*** Cracking of Concrete Ceiling - Air Exhaust Duct, Sunken Tube Tunnel**			
Observation:			
a. Hairline crack less than 1/16" open.	SF	1	
*** {Severity L}			
b. Open crack between 1/16" and 1/8" wide.	SF	1	
*** {Severity M}			
c. Open crack greater than 1/8" wide.	SF	1	7
*** {Severity H}			
Defect:			
*** Tunnel Liner Construction Joints - Air Exhaust Duct, Sunken Tube Tunnel**			
Observation:			
a. Joint separation less than 1/8" open.	LF	1	
*** {Severity L}			
b. Joint separation between 1/8" and 3/8" open.	LF	1	
*** {Severity M}			
c. Joint separation greater than 3/8" open.	LF	1	7
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.08 LIGHTING

Depending on the type of tunnel, light systems can include general tunnel lighting and emergency lighting. In general, vehicular tunnels have some type of lighting system while railroad and utility tunnels do not. Storage tunnels may or may not have a lighting system.

The purpose of the Level I tunnel structure inspection is to determine if the light system (if any) is operating at the time of inspection. Inspection of the electrical aspects of the light system should be performed by appropriate personnel in accordance with the written standards prepared for Exterior Lighting.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Electrical Systems/Lights - Tunnel**			
Observation:			
a. Individual lights not working.	EA		
*** {Severity M}			
b. Electrical system/lights not working.	EA		8
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.09 PORTALS

A portal is an entrance into the tunnel which does not involve a significant change in grade (i.e. unlike a shaft entrance). The portals are constructed at the end of the tunnels to protect and support the tunnel exits and entrances under masses of soil or rock; to prevent drainage infiltration into the tunnel and drain surface runoff water down the front slope; and to emphasize the structural significance of the tunnel through architectural features. Frequently, a horizontal berm will be constructed at some height over the portals in order to catch rockfall; provide surface runoff drainage; and provide a working platform for installing vertical rock reinforcement or instrumentation.

Portals can be divided into three categories, depending on anticipated ground behavior: 1) rock conditions are such that there is no need for a portal facade and the tunnel lining is extended and left exposed at the tunnel approaches; 2) if potential exists for rock falls or surface water seepage along the front slope, then a structural facade wall should be constructed around the entire opening; or 3) if earth pressures are expected from the front slope, then the portals must be designed as retaining walls. Any retaining walls lining the approach cuts can be considered as counterforts supporting the portal.

Portal facades can be constructed of a variety of materials including concrete, masonry block, or cut stone. Details concerning the type, configuration and composition of the portals can be obtained from the design or construction drawings.

Potential defects which can be observed during the inspection of a portal include structural defects including cracking, displacement, and deterioration; deterioration of rock reinforcement systems; slope stability problems; and seepage problems (covered in WBS 17.02). Retaining walls along the approach cuts should be inspected in accordance with written standards prepared for Retaining Walls.

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Surface Weathering - Right Portal Wall**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.09 PORTALS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Weathering - Left Portal Wall**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			
Defect:			
*** Surface Weathering - Portal Roof**			
Observation:			
a. Staining.	SF		
*** {Severity L}			
b. Efflorescence.	SF		
*** {Severity L}			
c. Plant growth.	SF		
*** {Severity L}			
Defect:			
*** Surface Deterioration (Concrete) - Right Portal Wall**			
Observation:			
a. Spalling, chipped concrete.	SF		
*** {Severity L}			
b. Cavitation.	SF		
*** {Severity L}			
c. Crazing.	SF		
*** {Severity L}			
Defect:			
*** Surface Deterioration (Concrete) - Left Portal Wall**			
Observation:			
a. Spalling, chipped concrete.	SF		
*** {Severity L}			
b. Cavitation.	SF		
*** {Severity L}			
c. Crazing.	SF		
*** {Severity L}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.09 PORTALS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Deterioration (Concrete) - Portal Roof**			
Observation:			
a. Spalling, chipped concrete.	SF		
*** {Severity L}			
b. Cavitation.	SF		
*** {Severity L}			
e. Crazing.	SF		
*** {Severity L}			
Defect:			
*** Surface Deterioration (Masonry or Cut Stone) - Right Portal Wall**			
Observation:			
a. Spalling, chipped masonry.	SF		
*** {Severity L}			
b. Missing joint mortar.	SF		
*** {Severity M}			
c. Damaged or missing rows of masonry.	SF		
*** {Severity M}			
d. Broken, damaged, loose, corroded or missing anchorage or fasteners.	EA		
*** {Severity H}			
Defect:			
*** Surface Deterioration (Masonry or Cut Stone) - Left Portal Wall**			
Observation:			
a. Spalling, chipped masonry.	SF		
*** {Severity L}			
b. Missing joint mortar.	SF		
*** {Severity M}			
c. Damaged or missing rows of masonry.	SF		
*** {Severity M}			
d. Broken, damaged, loose, corroded or missing anchorage or fasteners.	EA		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ 17.01.09 PORTALS (Continued)

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
* **Surface Deterioration (Masonry or Cut Stone) - Portal Roof**			
Observation:			
a. Spalling, chipped masonry.	SF		
*** {Severity L}			
b. Missing joint mortar.	SF		
*** {Severity M}			
c. Damaged or missing rows of masonry.	SF		
*** {Severity M}			
d. Broken, damaged, loose, corroded or missing anchorage or fasteners.	EA		
*** {Severity H}			
Defect:			
* **Surface Damage - Right Portal Wall**			
Observation:			
a. Punctures, holes, tears less than 3" in diameter.	SF		
*** {Severity L}			
b. Impact damage.	SF		
*** {Severity M}			
c. Punctures, holes, tears greater than 3" in diameter.	SF		
*** {Severity H}			
Defect:			
* **Surface Damage - Left Portal Wall**			
Observation:			
a. Punctures, holes, tears less than 3" in diameter.	SF		
*** {Severity L}			
b. Impact damage	SF		
*** {Severity M}			
c. Punctures, holes, tears greater than 3" in diameter.	SF		
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.09 PORTALS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Surface Damage - Portal Roof**			
Observation:			
a. Punctures, holes, tears less than 3" in diameter. *** {Severity L}	SF		
b. Impact damage *** {Severity M}	SF		
c. Punctures, holes, tears greater than 3" in diameter. *** {Severity H}	SF		
Defect:			
*** Cracking - Right Portal Wall**			
Observation:			
a. Cracks less than 1/4" open. *** {Severity L}	SF		
b. Cracks 1/4" to 1" open. *** {Severity M}	SF		
c. Cracks greater than 1" open. *** {Severity H}	LF		9
Defect:			
*** Cracking - Left Portal Wall**			
Observation:			
a. Cracks less than 1/4" open. *** {Severity L}	SF		
b. Cracks 1/4" to 1" open. *** {Severity M}	SF		
c. Cracks greater than 1" open. *** {Severity H}	LF		9

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.09 PORTALS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Cracking - Portal Roof**			
Observation:			
a. Cracks less than 1/4" open.	SF		
*** {Severity L}			
b. Cracks 1/4" to 1" open.	SF		
*** {Severity M}			
c. Cracks greater than 1" open.	LF		9
*** {Severity H}			
Defect:			
*** Movement/Displacement - Right Portal Wall**			
Observation:			
a. Movement, displacement, or settlement of wall less than 1/4".	SF		
*** {Severity L}			
b. Movement, displacement, or settlement of wall less than 1".	SF		
*** {Severity M}			
c. Movement, displacement, or settlement of wall greater than 1".	SF		9
*** {Severity H}			
Defect:			
*** Movement/Displacement - Left Portal Wall**			
Observation:			
a. Movement, displacement, or settlement of wall less than 1/4".	SF		
*** {Severity L}			
b. Movement, displacement, or settlement of wall less than 1".	SF		
*** {Severity M}			
c. Movement, displacement, or settlement of wall greater than 1".	SF		9
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.09 PORTALS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Movement/Displacement - Portal Roof**			
Observation:			
a. Movement, displacement, or settlement of wall less than 1/4".	SF		
*** {Severity L}			
b. Movement, displacement, or settlement of wall less than 1".	SF		
*** {Severity M}			
c. Movement, displacement, or settlement of wall greater than 1".	SF		9
*** {Severity H}			
Defect:			
*** Deterioration of Rock Reinforcement System - Right Portal Wall**			
Observation:			
a. Corroded rock reinforcement measures (rockbolts, rock dowels, anchors, anchor plates, etc.)	EA		
*** {Severity M}			
b. Loose or failed rock reinforcement measures (rockbolts, rock dowels, anchors, etc.)	EA		9
*** {Severity H}			
Defect:			
*** Deterioration of Rock Reinforcement System - Left Portal Wall**			
Observation:			
a. Corroded rock reinforcement measures (rockbolts, rock dowels, anchors, anchor plates, etc.)	EA		
*** {Severity M}			
b. Loose or failed rock reinforcement measures (rockbolts, rock dowels, anchors, etc.)	EA		9
*** {Severity H}			

17.01 TUNNEL STRUCTURE

COMPONENTS (Continued)

◆ **17.01.09 PORTALS (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Deterioration of Rock Reinforcement System - Portal Roof**			
Observation:			
a. Corroded rock reinforcement measures (rockbolts, rock dowels, anchors, anchor plates, etc.)	EA		
*** {Severity M}			
b. Loose or failed rock reinforcement measures (rockbolts, rock dowels, anchors, etc.)	EA		9
*** {Severity H}			
Defect:			
*** Slope Stability - Front Slope Above or Adjacent to Portal**			
Observation:			
a. Soil creep	SF		
*** {Severity L}			
b. Surface sloughing	SF		
*** {Severity L}			
c. Ground surface cracking	SF		
*** {Severity M}			
d. Rock falls	SF		9
*** {Severity H}			
e. Landslides	SF		9
*** {Severity H}			

17.01 TUNNEL STRUCTURE

REFERENCES

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973

2. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978

5. Transportation Research Record 883, Tunnel Ventilation, Lighting, and Operation, Transportation Research Board National Academy of Sciences, 1982

6. Cut-and-Cover Tunneling Techniques, Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973

7. Department of Energy CAS Manual, Section 0.12.03 Tunnels, (CSI 02300), Revised May, 1993

8. Alfonso Rico Rodriguez, Hermillo del Castillo, George F. Sowers, Soil Mechanics in Highway Engineering, 1988 Trans Tech Publication

17.01 TUNNEL STRUCTURE

LEVEL II KEY	GUIDE SHEET CONTROL NUMBER
1	GS-II 17.01.07-1

LEVEL III KEY	GUIDE SHEET CONTROL NUMBER
1	GS-III 17.01.01-1
2	GS-III 17.01.03-2
3	GS-III 17.01.04-3
4	GS-III 17.01.05-4
5	GS-III 17.01.06-5
6	GS-III 17.01.06-6
7	GS-III 17.01.07-7
8	GS-III 17.01.08-8
9	GS-III 17.01.09-9
10*	GS-III 17.01-10*
11*	GS-III 17.01-11*

* Indicates guide sheets which are not directly referenced by a Key. These are "triggered" by information beyond the inspection process such as time, age or repeated service calls.

LEVEL II INSPECTION METHOD GUIDE SHEET

LEVEL II GUIDE SHEET - KEY NO. 1

COMPONENT: VENTILATION SYSTEMS
CONTROL NUMBER: GS-II 17.01.07-1

Application

This guide has been prepared to identify the purpose of a Level II inspection of air supply ducts located below the roadway and exhaust air ducts located above the vehicular tunnel ceiling in sunken tube tunnels.

The results of the Level II inspection can be used to trigger a Level III inspection or necessary repair or remedial measure activities.

Inspection of any electrical or mechanical systems associated with the air supply or exhaust ducts shall be inspected by appropriate personnel in accordance with written standards.

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for prior notification of the Facility Manager or person responsible for the operation of the tunnel. The inspection personnel must check in with the above personnel upon completion of the inspection process.

Since the inspection of the air supply and exhaust ducts involves walking along sections of the tunnel secluded from the vehicular traffic lanes, it is recommended that the Level II inspection be performed with one or more support personnel accompanying the inspector during the inspection. If accompanying support personnel are not available, then the inspector must notify the person responsible for the tunnel operations that the inspection will be performed by only one inspector and provide an estimated time that the inspection will be completed. The single inspector must check in with the personnel responsible for the tunnel at the end of the inspection.

Inspection Items

1. Review operating procedures for the air supply and exhaust ducts.

2. Enter the air supply duct through the ventilation building access door.

3. Inspection of the air supply duct will require walking along a curved concrete floor section of the sunken tube tunnel. A bulkhead may be present which prohibits walking from portal to portal; in such case, inspection must proceed from both portals to the respective side of the bulkhead wall.

LEVEL II INSPECTION METHOD GUIDE SHEET

LEVEL II GUIDE SHEET - KEY NO. 1 (Continued)

COMPONENT: VENTILATION SYSTEMS
CONTROL NUMBER: GS-II 17.01.07-1

4. Inspection of the air supply duct includes observation for defects in the curved concrete bottom of the tunnel; cracks developed in the overhead vehicular concrete pavement slab; spalling along concrete encased electrical ducts; and corrosion and deterioration of structural steel beams oriented transverse to the roadway and supporting the concrete pavement slab.

5. Enter air exhaust duct over the vehicular tunnel via the ventilation building access door.

6. Inspection of the air exhaust duct will require walking along a concrete slab overlying the vehicular tunnel ceiling of the sunken tube tunnel. Typically, a bulkhead wall with door assembly exists which divides the duct into two sections between the portals.

7. Inspection of the air exhaust duct includes observations for defects in the underlying concrete slab and the curved concrete ceiling of the sunken tube tunnel. Potential defects include separation of tunnel construction joints; leakage through the tunnel roof; and cracking and superficial deterioration of the concrete floor slab and roof.

8. Notify Facility Manager immediately if seepage into the tunnel is observed.

Special Tools and Equipment Requirements

None.

References

1. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

2. Technical Committee on Tunnel Lining Design of the underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

3. Sverdrup Corporation Inspection Procedures for Annual Inspection of Chesapeake Bay Bridge - Tunnel, Virginia.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 1

COMPONENT: METAL PANEL TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.01-1

Application

This guide has been prepared to identify the purpose of a Level III inspection and its more sophisticated test and inspection methods which may be appropriate to determine the cause and/or extent of defects recorded in Level I or Level II defect observations of the metal panel tunnel wall and roof liner.

Whereas the purpose of the Level I inspection was to record the observable defects in the tunnel liner along the walls and roof of the tunnel, this Level III inspection is performed to provide a thorough systematic evaluation of the observed defect and to make an assessment of it's effects, if left unchecked, on the safety, durability and stability of the tunnel.

The Level III inspection should be performed when prompted by the results of a Level I or II inspection. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy that will correct the existing deficiency conditions or to require continued monitoring of existing deficiency conditions in the tunnel liner.

In general, appropriate advanced inspection methods will be identified, recommended, and performed by or under the supervision of the inspection engineer personnel as part of the Level III test and inspection method. Advanced inspection methods will be assigned only after the assessment of defect conditions observed during a Level I or II inspection.

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for the Standard Inspection of Tunnels. Any inspector using a lift truck or cherry picker shall wear a safety belt and have it secured to the lift equipment while inspection is being performed. See Master Safety Plan for additional comments.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 1 (Continued)

COMPONENT: METAL PANEL TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.01-1

Inspection Action

- Prior to making a field inspection of the observed defect, review all past records concerning the tunnel and the defective component if available. These records may include preconstruction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records, movement monument survey records, and photographs taken during initial construction and subsequent inspections.

- Perform inspection of the pertinent components where observed defects that triggered a Level III inspection are listed. Where observed defects are located in the tunnel walls or roof above standing height, use a lift truck, cherry picker, or other suitable equipment to allow the inspector to observe the defect at eye level. Mark the outer limits of observed defect with spray paint as necessary.

- Make an assessment of the importance of individual defects observed for a given component at the tunnel site. Indicate priorities for any required maintenance, or remedial measure work.

- Identify whether particular observed defects need additional or continued observation.

- Assess the stability and safety of the tunnel.

- Prepare final cost estimate for advanced inspection methods required to determine the cause and extent of the observed defect.

- Prepare cost estimate for required maintenance or repair measures, as applicable.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 1 (Continued)

COMPONENT: METAL PANEL TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.01-1

Level III advanced inspection methods may be required for several Level I and Level II defect conditions observed in metal panel tunnel liners. Level III advanced test or inspection methods and associated observed defects for metal panel tunnel liners include, but are not limited to the following:

Advanced Test or Inspection Method	Applicable Observed Defects
1. roof inspection (lift truck, scaffolding, etc.)	surface deterioration, surface damage, out-of-alignment, expansion joints
2. crack gauges	out-of-alignment, cracking
3. baroscope	out-of-alignment, expansion joints
4. rod extensometers	out-of-alignment
5. pressure cells	out-of-alignment, cracking
6. electrical strain gauges	out-of-alignment, cracking
7. infrared thermography	voids, seepage, out-of-alignment

Special Instructions

Review as-built and design drawings of structure.

Special Tools & Equipment Requirements

Equipment designated in Level I inspections
Survey Level and rod
Lift truck
Safety Belt
Spray paint
Small diameter (<1/2") steel probe rod
Industry required testing equipment needed to perform the advanced investigation method chosen

Recommended Inspection Frequency

Metal Panel Tunnel Liner - as needed basis

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 1 (Continued)

COMPONENT: METAL PANEL TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.01-1

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 2

COMPONENT: CONCRETE TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.03-2

Application

This guide has been prepared to identify the purpose of a Level III inspection and its more sophisticated test and inspection methods which may be appropriate to determine the cause and/or extent of defects recorded in Level I or Level II defect observations of the concrete tunnel wall and roof liner.

Whereas the purpose of the Level I inspection was to record the observable defects in the tunnel liner along the walls and roof of the tunnel, this Level III inspection is performed to provide a thorough systematic evaluation of the observed defect and to make an assessment of it's effects, if left unchecked, on the safety, durability and stability of the tunnel.

The Level III inspection should be performed when prompted by the results of a Level I or II inspection. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy that will correct the existing deficiency conditions or to require continued monitoring of existing deficiency conditions in the tunnel liner.

In general, appropriate advanced inspection methods will be identified, recommended, and performed by or under the supervision of the inspection engineer personnel as part of the Level III test and inspection method. Advanced inspection methods will be assigned only after the assessment of defect conditions observed during a Level I or II inspection.

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for the Standard Inspection of Tunnels. Any inspector using a lift truck or cherry picker shall wear a safety belt and have it secured to the lift equipment while inspection is being performed. See Master Safety Plan for additional requirements.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 2 (Continued)

COMPONENT: CONCRETE TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.03-2

Inspection Action

- Prior to making a field inspection of the observed defect, review all past records concerning the tunnel and the defective component if available. These records may include preconstruction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records, movement monument survey records, and photographs taken during initial construction and subsequent inspections.

- Perform inspection of the pertinent components where observed defects that triggered a Level III inspection are listed. Where observed defects are located in the tunnel walls or roof above standing height, use a lift truck, cherry picker, or other suitable equipment to allow the inspector to observe the defect at eye level. Mark the outer limits of observed defect with spray paint as necessary.

- Make an assessment of the importance of individual defects observed for a given component at the tunnel site. Indicate priorities for any required maintenance, or remedial measure work.

- Identify whether particular observed defects need additional or continued observation.

- Assess the stability and safety of the tunnel.

- Prepare final cost estimate for advanced inspection methods required to determine the cause and extent of the observed defect.

- Prepare cost estimate for required maintenance or repair measures, as applicable.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 2 (Continued)

COMPONENT: CONCRETE TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.03-2

Level III advanced inspection methods may be required for several Level I and Level II defect conditions observed in concrete tunnel liners. Level III advanced test or inspection methods and associated observed defects for concrete tunnel liners include, but are not limited to the following:

Advanced Test or Inspection Method	Applicable Observed Defects
1. roof inspection (lift truck, scaffolding, etc.)	surface deterioration, surface damage, out-of-alignment, expansion joints
2. crack gauges	out-of-alignment, cracking
3. baroscope	out-of-alignment, expansion joints
4. rod extensometers	out-of-alignment
5. pressure cells	out-of-alignment, cracking
6. electrical strain gauges	out-of-alignment, cracking
7. infrared thermography	voids, seepage, out-of-alignment
8. soil drilling/core drilling	surface deterioration, out-of-alignment
9. laboratory tests on soil samples	out-of-alignment, lining movement
10. concrete coring	concrete deterioration, out-of-alignment
11. laboratory tests on concrete cores (strength tests)	concrete deterioration
12. hand tool inspection for voids	out-of-alignment, seepage
13. survey measurements	out-of-alignment

Special Instructions

Review as-built and design drawings of structure.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 2 (Continued)

COMPONENT: CONCRETE TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.03-2

Special Tools & Equipment Requirements

Equipment designated in Level I inspections
Survey Level and rod
Lift truck
Safety Belt
Spray paint
Small diameter (<1/2") steel probe rod
Industry required testing equipment needed to perform the advanced investigation method chosen

Recommended Inspection Frequency

Concrete Tunnel Liner - as needed basis

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook,, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 3

COMPONENT: MASONRY TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.04-3

Application

This guide has been prepared to identify the purpose of a Level III inspection and its more sophisticated test and inspection methods which may be appropriate to determine the cause and/or extent of defects recorded in Level I or Level II defect observations of the masonry tunnel wall and roof liner.

Whereas the purpose of the Level I inspection was to record the observable defects in the tunnel liner along the walls and roof of the tunnel, this Level III inspection is performed to provide a thorough systematic evaluation of the observed defect and to make an assessment of it's effects, if left unchecked, on the safety, durability and stability of the tunnel.

The Level III inspection should be performed when prompted by the results of a Level I or II inspection. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy that will correct the existing deficiency conditions or to require continued monitoring of existing deficiency conditions in the tunnel liner.

In general, appropriate advanced inspection methods will be identified, recommended, and performed by or under the supervision of the inspection engineer personnel as part of the Level III test and inspection method. Advanced inspection methods will be assigned only after the assessment of defect conditions observed during a Level I or II inspection.

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for the Standard Inspection of Tunnels. Any inspector using a lift truck or cherry picker shall wear a safety belt and have it secured to the lift equipment while the inspection is being performed. See Master Safety Plan for additional requirements.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 3 (Continued)

COMPONENT: MASONRY TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.04-3

Inspection Action

- Prior to making a field inspection of the observed defect, review all past records concerning the tunnel and the defective component if available. These records may include preconstruction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records, movement monument survey records, and photographs taken during initial construction and subsequent inspections.

- Perform inspection of the pertinent components where observed defects that triggered a Level III inspection are listed. Where observed defects are located in the tunnel walls or roof above standing height, use a lift truck, cherry picker, or other suitable equipment to allow the inspector to observe the defect at eye level. Mark the outer limits of observed defect with spray paint as necessary.

- Make an assessment of the importance of individual defects observed for a given component at the tunnel site. Indicate priorities for any required maintenance or remedial measure work.

- Identify whether particular observed defects need additional or continued observation.

- Assess the stability and safety of the tunnel.

- Prepare final cost estimate for advanced inspection methods required to determine the cause and extent of the observed defect.

- Prepare cost estimate for required maintenance or repair measures, as applicable.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 3 (Continued)

COMPONENT: MASONRY TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.04-3

Level III advanced inspection methods may be required for several Level I and Level II defect conditions observed in masonry tunnel liners. Level III advanced test or inspection methods and associated observed defects for masonry tunnel liners include, but are not limited to the following:

Advanced Test or Inspection Method	Applicable Observed Defects
1. roof inspection (lift truck, scaffolding, etc.)	surface deterioration, surface damage, out-of-alignment
2. crack gauges	out-of-alignment, cracking
3. baroscope	out-of-alignment
4. rod extensometers	out-of-alignment
5. pressure cells	out-of-alignment, cracking
6. infrared thermography	voids, seepage, out-of-alignment
7. masonry drilling coring/drilling	surface deterioration, out-of-alignment
8. laboratory tests on soil samples	out-of-alignment, lining movement
9. hand tool inspection for voids	out-of-alignment, seepage, surface deterioration, voids
10. ground probing radar	out-of-alignment, voids
11. survey measurements	out-of-alignment

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 3 (Continued)

COMPONENT: MASONRY TUNNEL LINER
CONTROL NUMBER: GS-III 17.01.04-3

Special Instructions

Review as-built and design drawings of structure.

Special Tools & Equipment Requirements

Equipment designated in Level I inspections
Survey Level and rod
Lift truck
Safety Belt
Spray paint
Small diameter (<1/2") steel probe rod
Industry required testing equipment needed to perform the advanced investigation method chosen

Recommended Inspection Frequency

Masonry Tunnel Liner - as needed basis

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 4

COMPONENT: UNLINED TUNNEL
CONTROL NUMBER: GS-III 17.01.05-4

Application

This guide has been prepared to identify the purpose of a Level III inspection and its more sophisticated test and inspection methods which may be appropriate to determine the cause and/or extent of defects recorded in Level I or Level II defect observations of an unlined tunnel.

Whereas the purpose of the Level I inspection was to record the observable defects along the walls and roof of the tunnel, this Level III inspection is performed to provide a thorough systematic evaluation of the observed defect and to make an assessment of it's effects, if left unchecked, on the safety, durability and stability of the tunnel.

The Level III inspection should be performed when prompted by the results of a Level I or II inspection. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy that will correct the existing deficiency conditions or to require continued monitoring of existing deficiency conditions along the face of the unlined tunnel.

In general, appropriate advanced inspection methods will be identified, recommended, and performed by or under the supervision of the inspection engineer personnel as part of the Level III test and inspection method. Advanced inspection methods will be assigned only after the assessment of defect conditions observed during a Level I or II inspection.

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for the Standard Inspection of Tunnels. Any inspector using a lift truck or cherry picker shall wear a safety belt and have it tied to the lift equipment while inspection is being performed. See Master Safety Plan for additional requirements.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 4 (Continued)

COMPONENT: UNLINED TUNNEL
CONTROL NUMBER: GS-III 17.01.05-4

Inspection Action

- Prior to making a field inspection of the observed defect, review all past records concerning the tunnel and the defective component if available. These records may include preconstruction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records, movement monument survey records, and photographs taken during initial construction and subsequent inspections.

- Perform inspection of the pertinent components where observed defects that triggered a Level III inspection are listed. Where observed defects are located in the tunnel walls or roof above standing height, use a lift truck, cherry picker, or other suitable equipment to allow the inspector to observe the defect at eye level. Mark the outer limits of observed defect with spray paint as necessary.

- Make an assessment of the importance of individual defects observed for a given component at the tunnel site. Indicate priorities for any required maintenance, or remedial measure work.

- Identify whether particular observed defects need additional or continued observation.

- Assess the stability and safety of the tunnel.

- Prepare final cost estimate for advanced inspection methods required to determine the cause and extent of the observed defect.

- Prepare cost estimate for required maintenance or repair measures, as applicable.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 4 (Continued)

COMPONENT: UNLINED TUNNEL
CONTROL NUMBER: GS-III 17.01.05-4

Level III advanced inspection methods may be required for several Level I and Level II defect conditions observed in unlined tunnels. Level III advanced test or inspection methods and associated observed defects for unlined tunnels include, but are not limited to the following:

Advanced Test or Inspection Method	Applicable Observed Defects
1. roof inspection (lift truck, scaffolding, etc.)	surface weathering/deterioration, seepage, rock instability, deteriorated shotcrete liner
2. crack gauges	rock instability, shotcrete deterioration
3. Pressure cells	rock instability
4. rock coring/drilling	surface deterioration, weathering, rock instability
5. Hand tool inspection of rock or shotcrete liner	surface deterioration, rock instability, shotcrete deterioration

Special Instructions

Review as-built and design drawings of structure.

Special Tools & Equipment Requirements

Equipment designated in Level I inspections
Rock hammer
Lift truck
Safety Belt
Spray paint
Small diameter (<1/2") steel probe rod
Industry required testing equipment needed to perform the advanced investigation method chosen

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 4 (Continued)

COMPONENT: UNLINED TUNNEL
CONTROL NUMBER: GS-III 17.01.05-4

Recommended Inspection Frequency

Unlined tunnel - as needed basis

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 5

COMPONENT: TUNNEL FLOOR
CONTROL NUMBER: GS-III 17.01.06-5

Application

This guide has been prepared to identify the Level III Key 5 during a Level I tunnel inspection.

Level I tunnel inspection includes observing the condition of the tunnel floor for access as initially designed, as well as observing for signs of softening or floor heave. The purpose of the Level I tunnel inspection is to ensure that the tunnel floor is clear for vehicular traffic or rail traffic and to observe the condition of the tunnel floor if uncovered.

It is not intended that inspection of the pavement or trackwork system by a Level I tunnel inspector should be performed in lieu of a Level I inspection of the pavement or trackwork itself. These inspections must be performed by inspectors experienced in the inspection of such structures.

Selection of a Level III Key 5 for pavement or for trackwork indicates that obvious signs of deterioration or blockage were observed and that a specific Level I inspection should be performed to accurately measure and identify those conditions by appropriate inspection personnel.

Special Safety Requirements

Special safety requirements are as set forth in the written standards for trackwork and pavements.

Inspection Items

Inspection items shall be as set forth in the written standards for pavements and trackwork.

Special Tools and Equipment Requirements

Special tools and equipment requirements shall be as set forth in the written standards for pavements and trackwork.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 5 (Continued)

COMPONENT: TUNNEL FLOOR
CONTROL NUMBER: GS-III 17.01.06-5

Special Safety Equipment

Special safety requirements required for a Level I inspection of tunnel floors are found in the written standards for tunnels.

Recommended Inspection Frequency

Tunnel Floor as needed basis; inspection frequency as required for Trackwork and Pavements/Improved Surfaces where applicable

References

See written standards for pavements and trackwork.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 6

COMPONENT: TUNNEL FLOOR
CONTROL NUMBER: GS-III 17.01.06-6

Application

This guide has been prepared to identify the purpose of a Level III inspection and its more sophisticated test and inspection methods which may be appropriate to determine the cause and/or extent of defects recorded in Level I or Level II defect observations of an uncovered tunnel floor.

Whereas the purpose of the Level I inspection was to record the observable defects in the tunnel floor this Level III inspection is performed to provide a thorough systematic evaluation of the observed defect and to make an assessment of it's effects, if left unchecked, on the safety, durability and stability of the tunnel.

The Level III inspection should be performed when prompted by the results of a Level I or II inspection. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy that will correct the existing deficiency conditions or to require continued monitoring of existing deficiency conditions in the tunnel floor.

In general, appropriate advanced inspection methods will be identified, recommended, and performed by or under the supervision of the inspection engineer personnel as part of the Level III test and inspection method. Advanced inspection methods will be assigned only after the assessment of defect conditions observed during a Level I or II inspection.

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for the Standard Inspection of Tunnels.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 6 (Continued)

COMPONENT: TUNNEL FLOOR
CONTROL NUMBER: GS-III 17.01.06-6

Inspection Action

- Prior to making a field inspection of the observed defect, review all past records concerning the tunnel and the defective component if available. These records may include preconstruction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records, instrumentation records, and photographs taken during initial construction and subsequent inspections.

- Perform inspection of the pertinent components where observed defects that triggered a Level III inspection are listed. Mark the outer limits of observed defect with spray paint as necessary.

- Make an assessment of the importance of individual defects observed for a given component at the tunnel site. Indicate priorities for any required maintenance or remedial measure work.

- Identify whether particular observed defects need additional or continued observation.

- Assess the stability and safety of the tunnel.

- Prepare final cost estimate for advanced inspection methods required to determine the cause and extent of the observed defect.

- Prepare cost estimate for required maintenance or repair measures, as applicable.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 6 (Continued)

COMPONENT: TUNNEL FLOOR
CONTROL NUMBER: GS-III 17.01.06-6

Level III advanced inspection methods may be required for several Level I and Level II defect conditions observed along a tunnel floor. Level III advanced test or inspection methods and associated observed defects for tunnel floors include, but are not limited to the following:

Advanced Test or Inspection Method	Applicable Observed Defects
1. crack gauges	cracking, floor heave
2. rod extensometers	floor heave, settlement
3. pressure cells	out-of-alignment, cracking
4. rock coring/drilling	floor heave, softening
5. survey measurements	floor settlement, heave

Special Instructions

Review as-built and design drawings of structure.

Special Tools & Equipment Requirements

Equipment designated in Level I inspections
Survey Level and rod
Rock hammer
Spray paint
Small diameter (<1/2") steel probe rod
Industry required testing equipment needed to perform the advanced investigation method chosen

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 6 (Continued)

COMPONENT: TUNNEL FLOOR
CONTROL NUMBER: GS-III 17.01.06-6

Recommended Inspection Frequency

Unlined Tunnel Floor - as needed basis

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook,, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 7

COMPONENT: VENTILATION SYSTEM
CONTROL NUMBER: GS-III 17.01.07-7

Application

This guide has been prepared to identify the purpose of selection of a Level III Key 7 during inspection of ventilation systems during a Level I tunnel inspection and its more sophisticated test and inspection methods which may be appropriate to determine the cause and/or extent of defects recorded in Level I defect observations of the ventilation shaft.

The purpose of the Level I inspection of a natural tunnel ventilation system is to identify defects which are associated with observable sections of a ventilation shaft, if applicable. Whereas the purpose of the Level I inspection was to record the observable defects in the ventilation shaft, this Level III inspection is performed to provide a thorough systematic evaluation of the observed defect and to make an assessment of it's effects, if left unchecked, on the safety, durability and stability of the tunnel.

It is not intended that inspection of a mechanical ventilation system be performed by a Level I tunnel inspector. These inspections must be performed by inspectors experienced in the design and operation of such systems in accordance with the written standards for Ventilation.

Selection of a Level III Key 7 identifies that crack defect conditions observed in the ventilation shaft are such that performance of a Level III inspection should be performed by appropriate inspection personnel. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels and tunnel ventilation systems.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy that will correct the existing deficiency conditions or to require continued monitoring of existing deficiency conditions in the ventilation shaft.

In general, appropriate advanced inspection methods will be identified, recommended, and performed by or under the supervision of the inspection engineer personnel as part of the Level III test and inspection method. Advanced inspection methods will be assigned only after the assessment of defect conditions observed during a Level I or II inspection.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 7 (Continued)

COMPONENT: VENTILATION SYSTEM
CONTROL NUMBER: GS-III 17.01.07-7

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for the Standard Inspection of Tunnels. Any inspector using a lift truck or cherry picker shall wear a safety belt and have it secured to the lift equipment while inspection is being performed. Any inspector entering the ventilation shaft shall use such safety equipment and follow such safety precautions as required by OSHA or other agency having jurisdiction.

Inspection Action

- Prior to making a field inspection of the observed defect, review all past records concerning the tunnel and the defective ventilation shaft if available. These records may include pre-construction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records, instrumentation records, and photographs taken during initial construction and subsequent inspections.

- Perform inspection of the pertinent components where observed defects that triggered a Level III inspection are listed. Where observed defects are located in the ventilation shaft above standing height, use a lift truck, cherry picker, or other suitable equipment to allow the inspector to observe the defect at eye level. In extreme cases, inspection personnel may be required to be lowered down the shaft by cable mounted equipment to observe existing conditions. Mark the outer limits of observed defect with spray paint as necessary.

- Make an assessment of the importance of the individual defects observed in the ventilation shaft component at the tunnel site and assess whether such defect affects the natural ventilation process. Indicate priorities for any required maintenance or remedial measure work.

- Identify whether particular observed defects need additional or continued observation.

- Assess the stability and safety of the tunnel and the tunnel ventilation shaft.

- Prepare final cost estimate for advanced inspection methods required to determine the cause and extent of the observed defect.

- Prepare cost estimate for required maintenance or remedial repair measures, as applicable.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 7 (Continued)

COMPONENT: VENTILATION SYSTEM
CONTROL NUMBER: GS-III 17.01.07-7

Level III advanced inspection methods may be required for several Level I defect conditions observed in a ventilation shaft. Level III advanced test or inspection methods and associated observed defects for ventilation shafts include, but are not limited to the following:

Advanced Test or Inspection Method	Applicable Observed Defects
1. roof inspection (lift truck, scaffolding, etc.)	surface deterioration, surface damage, out-of-alignment, cracking
2. crack gauges	out-of-alignment, cracking
3. hand tool inspection	surface deterioration, cracking
4. coring/drilling	surface deterioration, out-of-alignment

Special Instructions

Review as-built and design drawings of structure.

Special Tools & Equipment Requirements

Equipment designated in Level I inspections
Lift truck
Safety Belt
Temporary lighting
Spray paint
Small diameter (<1/2") steel probe rod
Industry required testing equipment needed to perform the advanced investigation method chosen

Recommended Inspection Frequency

Ventilation System - as needed basis

LEVEL III GUIDE SHEET - KEY NO. 7 (Continued)

COMPONENT: VENTILATION SYSTEM
CONTROL NUMBER: GS-III 17.01.07-7

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

6. Transportation Research Record 883, Tunnel Ventilation, Lighting, and Operation Transportation Research Board National Academy of Sciences, 1982.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 8

COMPONENT: LIGHTING
CONTROL NUMBER: GS-III 17.01.08-8

Application

This guide has been prepared to identify the purpose of selection of a Level III Key 8 during inspection of lighting systems during a Level I tunnel inspection.

The purpose of the Level I inspection of the lighting system is to identify if the lights are operating satisfactorily at the time of inspection. It is not intended that inspection of the lights by a Level I tunnel inspector should be performed in lieu of a Level I inspection of the lighting system itself. These inspections must be performed by inspectors experienced in the design and operation of such systems.

Selection of a Level III Key 8 identifies that existing lighting system conditions are such that performance of an electrical system inspection should be performed by appropriate inspection personnel in accordance with the standards prepared for Exterior Lighting systems.

Special Safety Requirements

Special safety requirements are as set forth in the written standards for Exterior Lighting systems.

Inspection Items

Inspection items shall be as set forth in the written standards for Exterior Lighting systems.

Special Tools and Equipment Requirements

Special tools and equipment requirements shall be as set forth in the written standards for Building Substructure, Building Superstructure, Building Exterior, Building Electrical, and Electrical Distribution.

Special Safety Equipment

Special safety requirements required for a Level I inspection of a power structure facility is found in the written standards for Building Superstructure, Building Exterior, Building Electrical, and Electrical Distribution.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 8 (Continued)

COMPONENT: LIGHTING
CONTROL NUMBER: GS-III 17.01.08-8

Recommended Inspection Frequency

Lighting - as needed basis; inspection frequency as required for Exterior Lighting systems.

References

See written standards for Building Substructure, Building Superstructure, Building Exterior, Building Electrical, and Electrical Distribution.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 9

COMPONENT: PORTALS
CONTROL NUMBER: GS-III 17.01.09-9

Application

This guide has been prepared to identify the purpose of a Level III inspection and its more sophisticated test and inspection methods which may be appropriate to determine the cause and/or extent of defects recorded in Level I or Level II defect observations of the tunnel portals.

Whereas the purpose of the Level I inspection was to record observable defects at the tunnel portals, this Level III inspection is performed to provide a thorough systematic evaluation of the observed defect and to make an assessment of it's effects, if left unchecked, on the safety, durability and stability of the tunnel.

The Level III inspection should be performed when prompted by the results of a Level I or II inspection. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy that will correct the existing deficiency conditions or to require continued monitoring of existing deficiency conditions at the tunnel portal.

In general, appropriate advanced inspection methods will be identified, recommended, and performed by or under the supervision of the inspection engineer personnel as part of the Level III test and inspection method. Advanced inspection methods will be assigned only after the assessment of defect conditions observed during a Level I or II inspection.

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for the Standard Inspection of Tunnels. Any inspector using a lift truck or cherry picker shall wear a safety belt and have it tied to the lift equipment while inspection is being performed.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 9 (Continued)

COMPONENT: PORTALS
CONTROL NUMBER: GS-III 17.01.09-9

Inspection Action

- Prior to making a field inspection of the observed defect, review all past records concerning the tunnel portals and the defective component if available. These records may include preconstruction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records, movement monument survey records, and photographs taken during initial construction and subsequent inspections.

- Perform inspection of the pertinent components where observed defects that triggered a Level III inspection are listed. Where observed defects are located in the tunnel portal walls or roof above standing height, use a lift truck, cherry picker, or other suitable equipment to allow the inspector to observe the defect at eye level. Mark the outer limits of observed defect with spray paint as necessary.

- Make an assessment of the importance of individual defects observed at the tunnel portals. Indicate priorities for any required maintenance, or remedial measure work.

- Identify whether particular observed defects need additional or continue observation.

- Assess the stability and safety of the tunnel.

- Prepare final cost estimate for advanced inspection methods required to determine the cause and extent of the observed defect.

- Prepare cost estimate for required maintenance or repair measures, as applicable.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 9 (Continued)

COMPONENT: PORTALS
CONTROL NUMBER: GS-III 17.01.09-9

Level III advanced inspection methods may be required for several Level I and Level II defect conditions observed at tunnel portals. Level III advanced test or inspection methods and associated observed defects for metal panel tunnel liners include, but are not limited to the following:

Advanced Test or Inspection Method	Applicable Observed Defects
1. roof and upper wall inspection (lift truck, scaffolding,etc.)	surface deterioration, cracking, movement/displacement, rock reinforcement deterioration
2. crack gauges	movement/displacement, cracking
3. coring/drilling	surface deterioration, movement/displacement
4. soil borings	movement/displacement
5. laboratory tests on soil samples (strength tests, moisture content, Atterberg limits, etc.)	movement/displacement

Special Instructions

Review as-built and design drawings of structure.

Special Tools & Equipment Requirements

Equipment designated in Level I inspections
Survey Level and rod
Lift truck
Safety Belt
Rock hammer
Spray paint
Small diameter (< 1/2") steel probe rod
Industry required testing equipment needed to perform the advanced investigation method chosen

Recommended Inspection Frequency

Tunnel Portal - as needed basis

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 9 (Continued)

COMPONENT: PORTALS
CONTROL NUMBER: GS-III 17.01.09-9

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook,, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY 10*

SUBSYSTEM: TUNNEL STRUCTURE
CONTROL NUMBER: GS-III 17.01-10*

Application

This guide has been prepared to identify the purpose of a regularly scheduled Level III inspection of tunnel and portal structures.

Whereas the purpose of the Level I inspection was to record the condition of observable defects at readily accessible components of the tunnel, the Level III inspection is performed to provide a thorough systematic evaluation of the physical condition of the tunnel and portals, and an assessment of the safety and stability of the project structures.

The Level III inspection also includes inspection of conditions along the roof and upper wall sections of the tunnel. Such inspection will require the use of a lift truck, cherry picker or other appropriate equipment. Localized hand tool inspection for roads or deteriorated tunnel liner sections should be performed locally in areas where such defects are readily identifiable.

This type of Level III inspection should be performed on a regularly scheduled basis. The inspection should be performed by an engineer or multi-disciplined team of engineers experienced in the design and construction of tunnels.

The written standards developed for Level I inspection can be used as a guide or outline to be followed during the regularly scheduled Level III inspection. The primary difference between the two types of inspections is that an assessment of an observed condition with respect to degree of severity and to the stability and safety of the tunnel is made and an assessment can be made to indicate which maintenance or remedial measure work is the most important to be completed for the particular project site.

The results of the Level III inspection will be used to develop maintenance or remedial measure work strategy to correct existing deficiency conditions or result in continued monitoring of existing conditions at the tunnel.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY 10* (Continued)

SUBSYSTEM: TUNNEL STRUCTURE
CONTROL NUMBER: GS-III 17.01-10*

Special Safety Requirements

Special safety requirements are as set forth in the standards developed for Standard Inspection of Tunnels.

For entry into any tunnel, the inspection team shall consists of a minimum of two personnel. Any person entering the tunnel must have the safety equipment and follow such safety measures as required by OSHA and all other agencies having jurisdiction.

Any inspector using a lift truck or cherry picker to observe roof or upper wall defects shall wear a safety belt and have it secured to the lift equipment while the inspection is being performed.

Inspection Action

1. Prior to performing the field inspection, review all past records concerning the tunnel if available. These records may include pre-construction investigation records, design criteria and analysis records, available construction records, previous periodic maintenance inspection records,instrumentation, and photographs taken during initial construction and subsequent inspections.

2. Perform inspection of all pertinent components listed in the written standards for a Level I inspection of a tunnel structure.

3. Inspect the roof and upper wall sections of the tunnel which require the use of a lift truck or other equipment to observe conditions at near-eye level.

4. Inspect air exhaust and supply vents of sunken tube tunnels where applicable.

5. Identify whether particular observed defects need to be further investigated per non-standard test or inspection methods as set forth in GS-III 17.01-1 through GS-III 17.01.01-9, or if continued observation is appropriate. Engineer(s) to identify and plan appropriate advanced test or inspection method and supervise performance of the inspection when applicable.

** This Guide Sheet is not referenced by a Key, but may be "triggered" by conditions beyond the inspection process such as time, age, or repeated service calls.*

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY 10* (Continued)

SUBSYSTEM: TUNNEL STRUCTURE
CONTROL NUMBER: GS-III 17.01-10*

Inspection Action (Continued)

7. Make an assessment of the importance of individual defects observed at the tunnel site. Indicate priorities for any required maintenance, additional investigations, and/or remedial measure work.

8. Assess the stability and safety of the tunnel.

9. Prepare cost estimates for advanced test or inspection methods to determine the cause and extent of observable defect(s) which may impact the stability of the tunnel.

10. Prepare cost estimates for required maintenance or remedial repair measures, as applicable.

Special Tools and Equipment Requirements

Equipment designated in Level I inspections
Lift truck, cherry picker, or similar equipment
Safety belt
Rock hammer
Spray paint
Standard testing equipment required to perform the non-standard test or investigation method

Recommended Inspection Frequency

Regularly Scheduled Level III Inspection - 5 year intervals

References

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

** This Guide Sheet is not referenced by a Key, but may be "triggered" by conditions beyond the inspection process such as time, age, or repeated service calls.*

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY 10* (Continued)

SUBSYSTEM: TUNNEL STRUCTURE
CONTROL NUMBER: GS-III 17.01-10

References (Continued)

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Cut-and-Cover Tunneling Techniques Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

6. Transportation Research Record 833, Tunnel Ventilation, Lighting and Operation, Transportative Research Board National Academy of Services, 1982.

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY 11*

SUBSYSTEM: TUNNEL STRUCTURE
CONTROL NUMBER: GS-III 17.01-11*

Application

This guide has been prepared to identify the purpose of a Level III inspection of small diameter (less than 48" diameter) or inaccessible utility tunnels using remote control closed circuit TV camera inspection techniques. The inspection will be performed to provide a videotape record of the internal condition of the tunnel and to detect any observable areas of leakage, blockage, or soil infiltration.

The results of the Level III inspection can be used to develop and perform advanced testing measures or to trigger necessary repair or remedial measure activities.

Special Safety Requirements

Opening access manhole covers or cutting into small diameter tunnels to gain access may result in the release of airborne gases. Therefore, it may be necessary to let the access remain open for some time period or to monitor the air quality prior to placing the remote control or television monitoring equipment into the pipe. Such efforts shall be in accordance with all OSHA requirements and any authority having jurisdiction over the utility tunnel.

If personnel enter the small diameter pipe, special safety equipment and appropriate air quality monitoring equipment shall be used as required by OSHA or authority having jurisdiction over the utility tunnel.

Inspection of small diameter tunnels must be performed only after prior notification of the Facility Manager or person responsible for the tunnel. The inspection personnel must check in with the above personnel upon completion of the inspection process.

A minimum of two personnel is required to be at the inspection site during inspection of small diameter tunnels. The second person should be one who is completely familiar with the function and operation of the tunnel site.

* *This Guide Sheet is not referenced by a Key, but may be "triggered" by conditions beyond the inspection process such as time, age, or repeated service calls.*

LEVEL III INSPECTION METHOD GUIDE SHEET

LEVEL III GUIDE SHEET - KEY 11* (Continued)

SUBSYSTEM: TUNNEL STRUCTURE
CONTROL NUMBER: GS-III 17.01-11*

Inspection Items

- Review existing design or construction drawings and operating instructions for the tunnel, if available.
- Keep permanent record of access location, starting point reference location (stationing), direction of inspection, and intervals and units of baseline used for determining location during the inspection.
- Use a remote controlled revolving 360 degree TV camera to record existing conditions along the interior of the small diameter tunnel. The monitoring system must be capable of determining and recording exact location along the length of the tunnel. The lighting provided and/or the filming equipment utilized should be capable of producing a videotape picture quality sufficiently clear that the internal condition of the tunnel can be assessed.
- Inspectors shall prepare a letter report summarizing the results of the TV camera inspection and provide a copy of the tunnel inspection videotape to the Facility Manager for permanent record.

Special Tools and Equipment Requirements

Equipment designated for use in remote control TV inspection of small diameter tunnels

Required Inspection Frequency

Remote Control TV Inspection of Small Diameter Tunnels - 2 year intervals

References

1. Scott Air Force Base, Sewer System Evaluation Survey, Phase II, Report prepared by Sverdrup Corporation for HQ AMC, Scott Air Force Base, 1993.

17.02 TUNNEL DRAINAGE

DESCRIPTION

A drainage system is an essential part of the successful operation of vehicular, railroad, or pedestrian tunnel. Tunnel drainage systems are required to combat water which enters the tunnel through surface runoff and generated in the tunnel due to washing of walls and ceiling. A sizeable quantity of water removal could be required in case of fire needing fire-fighting effort. Another source of water in the tunnel is the seepage of surrounding outside water into the tunnel through cracks in walls and ceilings or through the floor. Moisture drippings from vehicles are also a source of water in the tunnel that requires removal.

Drainage requirements for roadway and pedestrian tunnels are somewhat different from those of a railway tunnel. For roadways and pedestrian tunnels, the drainage system is designed to operate with either gravity flow or with pumped flow. Gravity flow system is generally of open type, or closed type. Selection of a drainage system is dependent on the tunnel grade. Sunken tube tunnels almost always have a low point within the tunnel, thus requiring a pumping system to remove the water. A tunnel with same grade throughout its alignment could accommodate a gravity-flow system if water can be disposed of at the lower end. Railway tunnels include a drainage system which collects water in a continuous perforated pipe embedded below the trackbed ballast. Some designs for transit train tunnels do not require the use of ballast. In such cases, the drainage system consists of open channel flow to inlets leading to a pumping arrangement.

SPECIAL TOOL AND EQUIPMENT REQUIREMENTS

No special tools are needed for the Level I and Level II inspection of the tunnel drainage components beyond the requirements listed in the Standard Tools Section except for the following:

Lightweight Life Safety System
Hard hat with miners lamp and battery pack
Portable lighting system, when required
Spray paint: for marking

SPECIAL SAFETY REQUIREMENTS

The following special safety requirements, beyond those listed in the Master Safety Plan and System Safety Section are necessary to perform the inspection of the Tunnel Drainage.

Inspectors should coordinate with the Facility Manager to utilize the installations notification procedure to secure safe access to the Tunnel. Additional signage may be required in some circumstances based on traffic/rail traffic flow and the requirements of the Master Safety Plan.

COMPONENT LIST

- 17.02.01 OPEN GRAVITY FLOW
- 17.02.02 CLOSED GRAVITY FLOW
- 17.02.03 PUMPED FLOW

17.02 TUNNEL DRAINAGE

RELATED SUBSYSTEMS

Due to the related nature of the elements requiring inspection, the following should be reviewed for concurrent inspection activities.

23.03 STORM WATER COLLECTION SYSTEM

STANDARD INSPECTION PROCEDURE

The inspection shall be carried out for each drainage type listed. The inspector will identify types of physical distresses existing in the drainage system; and measure the quantity of each distress. The observation contains the description of each distress at low, medium and high level of severity. For Level III inspection items, refer to Level III Guide Sheets for inspection procedure.

17.02 TUNNEL DRAINAGE

COMPONENTS

♦ 17.02.01 OPEN GRAVITY FLOW

For roadway and pedestrian tunnels, the drainage system consists of a curb and gutter arrangement. The gutter is generally recessed and acts as a channel. Water collected from rainfall, tunnel washing, seepage/leakage, drippings from vehicles, and fire fighting effort is carried in an open channel by gravity flow to a discharge point at some location away from the tunnel. Open gravity flow is possible only if grade permits.

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Debris Accumulation within the Gutter Channel**			
Observation:			
a. Isolated debris accumulated along the gutter *** {Severity L}	LF		
b. Gutter channel less than 50% blocked by debris *** {Severity M}	LF		
c. Gutter channel more than 50% blocked by debris *** {Severity H}	LF		
Defect:			
*** Damaged Gutters**			
Observation:			
a. Longitudinal/transverse cracks- not spalled *** {Severity L}	LF		
b. Longitudinal/transverse cracks- spalled *** {Severity M}	LF		
c. Broken loose concrete pieces *** {Severity H}	LF		
Defect:			
*** Damaged Curbs**			
Observation:			
a. Longitudinal/transverse cracks- not spalled *** {Severity L}	LF		
b. Longitudinal/transverse cracks- spalled *** {Severity M}	LF		
c. Broken loose concrete pieces *** {Severity H}	LF		

17.02 TUNNEL DRAINAGE

COMPONENTS (Continued)

◆ 17.02.02 CLOSED GRAVITY FLOW

A closed gravity flow drainage system consists of longitudinal and lateral drainage pipes with a sufficient number of inlets located at the curb line to transmit water into the pipe. Cleanouts are provided at suitable intervals to minimize pipe blocking and to permit pipe cleaning. Water collected from rainfall, tunnel washing, seepage/leakage, drippings from vehicles, and fire fighting effort is carried in pipes by gravity to a discharge point somewhere away from the tunnel. Closed gravity flow is possible only if grade permits.

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Defective Drainage Inlet Covers**			
Observation:			
a. Damaged cover, performs satisfactorily	EA		
*** {Severity L}			
b. Broken cover, lets debris in	EA		
*** {Severity M}			
c. Missing cover	EA		
*** {Severity H}			
Defect:			
*** Debris Accumulation within the Inlet**			
Observation:			
a. Isolated debris accumulated	EA		
*** {Severity L}			
b. Inlet less than 25% blocked by debris	EA		
*** {Severity M}			
c. Inlet more than 25% blocked by debris	EA		
*** {Severity H}			

17.02 TUNNEL DRAINAGE

COMPONENTS (Continued)

◆ **17.02.02 CLOSED GRAVITY FLOW (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Debris Accumulation within the Drainage Pipe**			
Observation:			
a. Isolated debris accumulated in drains	LF		
*** {Severity L}			
b. Drain functions, but slow drainage from inlet and cleanout	LF		
*** {Severity M}			
c. Damaged or clogged drain pipe	LF		1
*** {Severity H}			
Defect:			
*** Defective Cleanout Covers**			
Observation:			
a. Damaged cover, performs satisfactorily	EA		
*** {Severity L}			
b. Broken cover, lets debris in	EA		
*** {Severity M}			
c. Missing cover	EA		
*** {Severity H}			
Defect:			
*** Debris Accumulation within the Cleanout**			
Observation:			
a. Isolated debris accumulated in cleanout	EA		
*** {Severity L}			
b. Cleanout less than 25% blocked by debris	EA		
*** {Severity M}			
c. Cleanout more than 25% blocked by debris	EA		
*** {Severity H}			

17.02 TUNNEL DRAINAGE

COMPONENTS (Continued)

◆ 17.02.03 PUMPED FLOW

Tunnels with grades that do not permit the use of gravity flow drains are equipped with pipe drains and one or more pump stations that collect the water at low points from rainfall, tunnel washing, seepage/leakage, drippings from vehicles, and fire fighting effort, and pump it out the tunnel. In general, the pump stations are provided at low points in the tunnel and at tunnel portals. Inspection of pumps shall be conducted in accordance with WBS 23.03.02 and 23.03.03.

Defect:	UOM	LEVEL II KEY	LEVEL III KEY
*** Defective Drainage Inlet Covers**			
Observation:			
a. Damaged cover, performs satisfactorily	EA		
*** {Severity L}			
b. Broken cover, lets debris in	EA		
*** {Severity M}			
c. Missing cover	EA		
*** {Severity H}			
Defect:			
*** Debris Accumulation within the Inlet**			
Observation:			
a. Isolated debris accumulated	EA		
*** {Severity L}			
b. Inlet less than 25% blocked by debris	EA		
*** {Severity M}			
c. Inlet more than 25% blocked by debris	EA		
*** {Severity H}			
Defect:			
*** Debris Accumulation within the Drainage Pipe**			
Observation:			
a. Isolated debris accumulated in drains	LF		
*** {Severity L}			
b. Drain functions, but slow drainage from inlet and cleanout to sump	LF		
*** {Severity M}			
c. Damaged or clogged drain pipe	LF		2
*** {Severity H}			

17.02 TUNNEL DRAINAGE

COMPONENTS (Continued)

◆ **17.02.03 PUMPED FLOW (Continued)**

Defect:	UOM	LEVEL II KEY	LEVEL ■ KEY
*** Defective Cleanout Covers**			
Observation:			
a. Damaged cover, performs satisfactorily	EA		
*** {Severity L}			
b. Broken cover, lets debris in	EA		
*** {Severity M}			
c. Missing cover	EA		
*** {Severity H}			
Defect:			
*** Debris Accumulation within the Cleanout**			
Observation:			
a. Isolated debris accumulated in cleanout	EA		
*** {Severity L}			
b. Cleanout less than 25% blocked by debris	EA		
*** {Severity M}			
c. Cleanout more than 25% blocked by debris	EA		
*** {Severity H}			
Defect:			
*** Pump Control System**			
Observation:			
a. Control system performs but with loose connections and/or missing parts	EA		
*** {Severity L}			
b. Control system not operating	EA		
*** {Severity H}			
Defect:			
*** Pump Operations**			
Observation:			
a. Pumps not operational at time of inspection	EA		
*** {Severity H}			

17.02 TUNNEL DRAINAGE

REFERENCES

1. Szechy, K., The Art of Tunnelling, Akademiai Kiado - Publishing House of the Hungarian Academy of Sciences, 1973.

2. Tunnel Engineering Handbook, edited by J.O. Bickel and T.R. Kuesel, Van Nostrand Reinhold Company, 1982.

3. Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, Guidelines for Tunnel Lining Design, edited by T.D. O'Rourke, American Society of Civil Engineers, 1984.

4. EM 1110-2-2901, Tunnels and Shafts in Rock, September 15, 1978.

5. Transportation Research Record 883, Tunnel Ventilation, Lighting, and Operation, Transportation Research Board National Academy of Sciences, 1982.

6. Cut-and-Cover Tunneling Techniques, Report No. FHWA-RD-73-40. Prepared by Sverdrup & Parcel and Associates, Inc. for the Federal Highway Administration Offices of Research & Development, 1973.

7. Department of Energy CAS Manual, Section 0.12.03 Tunnels. (CSI 02300), Revised May 1993.

17.02 TUNNEL DRAINAGE

LEVEL II KEY GUIDE SHEET CONTROL NUMBER

N/A

LEVEL III KEY	GUIDE SHEET CONTROL NUMBER
1	GS-III 17.02.02-1
2	GS-III 17.02.03-2

LEVEL III INSPECTION GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 1

COMPONENT: CLOSED GRAVITY FLOW
CONTROL NUMBER: GS-III 17.02.02-1

Application

This guide applies to a closed circuit TV inspection of inaccessible small diameter drainage pipes to provide a video tape record of the internal condition of the drain and to detect any observable areas of leakage, blockage, or soil infiltration.

Special Safety Equipment

Since personnel will not be entering the small diameter drainage pipe, there is no special safety equipment required for this Level III inspection.

Special Safety Requirements

Level III inspection and testing must be performed with the prior approval of the Facility Manager who will notify the authorities to provide safety measures and safe access.

Inspection Actions

- Keep permanent record of access location, starting point reference location (stationing), direction of inspection, and intervals and units of baseline used for determining location during the inspection.
- Utilize a remote controlled revolving 360 degree TV camera to record existing conditions. The monitoring system must be capable of determining and recording exact location along the length of the drain. The lighting provided and/or the filming equipment utilized, shall be capable of producing a video tape picture quality sufficiently clear that the internal condition of the drain can be assessed.
- Drainage pipe should be accessed for TV camera placement at inlets and/or cleanouts.
- A letter report shall be prepared summarizing the results of the inspection and a copy of the tunnel inspection videotape shall be provided to the Facility Manager for permanent record.
- All reports and videotapes submitted to the Facility Manager for permanent records.

LEVEL III INSPECTION GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 1 (Continued)

COMPONENT: CLOSED GRAVITY FLOW
CONTROL NUMBER: GS-III 17.02.02-1

Special Tools and Equipment

Standard TV monitoring and recording equipment required for inspection of the inside of small diameter drains as defined in Inspection Action above.

Recommended Inspection Frequency

Level III inspection will be performed when triggered by the defect "Debris Accumulation within the Drainage Pipe", and routinely every five (5) years.

References

1. Scott Air Force Base, Sewer System Evaluation Survey, Phase II, Report Prepared by Sverdrup Corporation for HQ AMC, Scott Air Force Base, 1993

LEVEL III INSPECTION GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 2

COMPONENT: CLOSED GRAVITY FLOW
CONTROL NUMBER: GS-III 17.02.03-2

Application

This guide applies to a closed circuit TV inspection of inaccessible small diameter drainage pipes to provide a video tape record of the internal condition of the drain and to detect any observable areas of leakage, blockage, or soil infiltration.

Special Safety Equipment

Since personnel will not be entering the small diameter drainage pipe, there is no special safety equipment required for this Level III inspection.

Special Safety Requirements

Level III inspection and testing must be performed with the prior approval of the Facility Manager who will notify the authorities to provide safety measures and safe access.

Inspection Actions

- Keep permanent record of access location, starting point reference location (stationing), direction of inspection, and intervals and units of baseline used for determining location during the inspection.
- Utilize a remote controlled revolving 360 degree TV camera to record existing conditions. The monitoring system must be capable of determining and recording exact location along the length of the drain. The lighting provided and/or the filming equipment utilized, shall be capable of producing a video tape picture quality sufficiently clear that the internal condition of the drain can be assessed.
- Drainage pipe should be accessed for TV camera placement at inlets and/or cleanouts.
- A letter report shall be prepared summarizing the results of the inspection and a copy of the tunnel inspection videotape shall be provided to the Facility Manager for permanent record.
- All reports and videotapes submitted to the Facility Manager for permanent records.

LEVEL III INSPECTION GUIDE SHEET

LEVEL III GUIDE SHEET - KEY NO. 2 (Continued)

COMPONENT: CLOSED GRAVITY FLOW
CONTROL NUMBER: GS-III 17.02.03-2

Special Tools and Equipment

Standard TV monitoring and recording equipment required for inspection of the inside of small diameter drains as defined in Inspection Action above.

Recommended Inspection Frequency

Level III inspection will be performed when triggered by the defect "Debris Accumulation within the Drainage Pipe", and routinely every five (5) years.

References

1. Scott Air Force Base, Sewer System Evaluation Survey, Phase II, Report Prepared by Sverdrup Corporation for HQ AMC, Scott Air Force Base, 1993

APPENDIX A

ABBREVIATIONS

EA	Each
FT	Feet
GPM	Gallons Per Minute
GS-II	Guide Sheet, Level II Inspection Method
GS-III	Guide Sheet, Level III Inspection Method
IN	Inches
LF	Linear Feet
SF	Square Feet
UOM	Unit of Measure
<	Less Than
>	Greater Than

APPENDIX B

GLOSSARY
DESCRIPTION OF TUNNEL TERMS

Adit	A short transverse tunnel connecting two parallel tunnels or an entry from the face of the slope to a sidehill tunnel.
Arch	The configuration of the upper portion of a tunnel section above the springline; the crown, roof, or back of a tunnel.
Brick/Masonry Arch Tunnel	Tunnels constructed by cut and cover techniques, composed of steel framing spaced approximately 8 feet on-center for walls and 4 feet on-center for roof sections. The spaces between the steel framing are filled with brick in an arch shape. The brick and ceiling vaults are usually 24 inches thick and are covered with pitch on the exterior surface for waterproofing.
Circular Tunnels	A tunnel of circular cross section consisting of pre-cast concrete segments. The void between the concrete liner and the earth is normally filled with gravel packing or grout.
Crown	The highest part of a circular or horseshoe-shaped tunnel.
Dry Packing	Filling a void with stiff mortar, placed in small increments, or gravel packed into the space between rock excavation, and poured in place tunnel lining to permit drainage of seepage water.
Extensometer	A device for precisely measuring the convergence or divergence of reference points along a common axis.
Gunite	Pneumatically placed mortar, often used to prevent air slaking of a tunnel's excavated surface; also applied as a support either directly on the excavated surface or over other supports to strengthen them. Usually with aggregate smaller than one-half inch diameter.
Invert	The invert is the bottom portion of the arc of a circular- or horseshoe-shaped tunnel. In a flat bottom tunnel the inverse is the bottom of the tunnel.
Joints (Tunnel Liner)	A contact surface or separation between adjacent segments of a tunnel lining.
Lagging	Timber planks, steel plates or other materials inserted above tunnel-supporting ribs to hold soil or rock.
Liner Plates	Metal plates which are fastened together to support the arch, sides, and, in some cases, the invert of a tunnel.

APPENDIX B

Lining	A temporary or permanent concrete structure to secure and finish the tunnel interior.
Mixed Face	The portion of a tunnel where both rock and soft ground occur in the same cross-section.
Mixed Face Tunnel	Tunnels with part of their cross-section in rock and part in soft ground, with the rock interface often weathered and frequently difficult to construct.
Panning	A water deflecting or channeling device, usually made of sheet metal, which is attached to the tunnel walls or arch to direct ground water infiltration to a sump or pipe to protect the fluid concrete from water percolating through it.
Portal	An entrance, not involving a sudden change in gradient, to a tunnel.
Ribs	A part of the tunnel support, usually of structural steel, curved to suit the shape of the tunnel section.
Rock Anchor	An untensioned reinforcement element consisting of a rod embedded in a mortar or grout filled hole.
Rock Bolts	Steel bolts inserted and anchored in boreholes around the periphery of a tunnel excavation to hold rock in place. A tensioned reinforcement element consisting of a rod, a mechanical or grouted anchorage, and a plate and nut for tensioning by torquing the nut or for retaining tension applied by direct pull.
Rock Dowel	Rock reinforcement, usually a reinforcing bar, that is inserted untensioned and fully grouted in place in a borehole.
Rock Reinforcement	The placement of rock bolts, rock anchors, rock dowels, or tendons at a fairly uniform spacing to consolidate the rock and reinforce the rock's natural tendency to support itself. Frequently used in conjunction with shotcrete on a rock surface. Rock reinforcement element is a general term for rock bolts, tendons, and rock anchors.
Rock Tendon (Prestressed)	Tensioned reinforcing elements, generally of higher capacity than a rock bolt, consisting of a high strength steel tendon (made up of one or more wires, strands or bars) fitted with a stressing anchorage at one end and a means permitting force transfer to the grout and rock at the other end.

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Rock Tunnels	Tunnels excavated in a firm, cohesive medium which may vary from relatively soft marl and sandstone to very hard igneous rock. Bedding and fissuring of rock layers, and the presence of water, control construction methods and difficulties.
Roof	The overhead portion of a tunnel or excavation.
Segmental Lining	Tunnel lining made of sections which fit together to form a ring; commonly of steel, cast iron, or precast concrete. Segments may be bolted together, or keyed together without bolts.
Segmental Steel Line Tunnel	A steel liner acts as the exterior walls, floor, and roof of the tunnel, and the flanges of the liner plate act as the steel framing or ribs. The void between the steel liner and the earth is normally filled with gravel packing or grout.
Shaft	A vertical excavation to gain access to tunnels or mines from the surface. Liners are frequently used to stabilize and provide interior finishes.
Shield Tunnel	Tunnels constructed in soft, unstable soil, where steel shields (circular) are driven through the ground and then excavated. Substrate conditions requiring shield tunnels include weak non-cohesive soil, weak plastic soils, clays and soils under water pressure.
Shotcrete	Pneumatically placed concrete; a mixture of sand, gravel, cement, and water which is projected with compressed air against the ground. Accelerating agents may be added to speed hardening of the concrete.
Soft Ground Tunnels	Tunnels built in soft, plastic or non-cohesive soils where water may or may not be a problem.
Struts	Compression supports placed between tunnel sets; includes structural members placed transversely across the tunnel centerline near the invert to prevent inward movement of structural steel ribs.
Sunken Tube Tunnels	Tunnels employed to cross bodies of water; consist of tube sections (concrete or steel) designed in convenient lengths which are fabricated and then lowered into prepared tunnel trenches.
Tunnel	An underground structure of relatively uniform cross-section and significant length used for purposes of transportation, shelter, or storage.

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Tunnel Drainage	Tunnel drainage can be achieved through a gravity flow or pumped system. Gravity drainage systems are used for tunnels with continuous grade, provided that the water can be collected and disposed of at the tunnel portals. Tunnels that change grade require a pumping system to control drainage, unless two gravity drainage systems are used.
(Open Drainage System)	A drainage system with gutters recessed into the curb.
(Closed Drainage System)	A drainage system where drainage flow enters inlets at the curb lines, then passes through a closed gravity flow system.
Tunnel Finish	All tunnels, except those mined through stable rock, require a structural lining. In most cases, the tunnel lining interior surface will also serve as the finish. Exceptions include highway tunnels, where tile is usually placed over the interior lining face.
(Cast-in-Place Concrete)	The ceiling slab consists of reinforced concrete 4 to 6 inches thick, which usually span transversely between the tunnel walls and supports. Interior spans vary. Composite concrete and structural beams or steel stringers, located between hangers spaced at 4 to 12 foot centers, provide the main support.
(Metal Panel Ceiling)	Metal ceiling panels consisting of cold-formed steel or aluminum panel filled with concrete. Panels vary from 2 to 4 inches thick, 6 to 13 feet long, and 1.5 to 2.5 feet wide. Porcelain finished are often applied to panel soffits and sides. These ceilings are usually supported by means of hangers, string supports, and frames. Widely used in highway tunnels.
(Veneered Ceilings)	Veneer finish directly applied to the structural tunnel lining. Typical veneer finished include ceramic tile (most common), metal panels, paints, and specialty coatings.
(Sidewall Finishes)	The tunnel's structural lining usually forms the wall finish. If called for, typical sidewall finishes include paint, ceramic tile, and cast concrete patterns. Sidewall finishes should be smooth to avoid ventilation and reduce friction loss.
Water Stop	A rubber elastomeric or rigid device placed and anchored across a joint cast in concrete to impede passage of water through the joint.

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GLOSSARY
DESCRIPTION OF TUNNEL DEFECTS

Alkali-Silica Aggregate Reaction	The alkali-silica aggregate reaction is a chemical reaction between aggregate and cement paste causing separation and bond break-up. The reaction can occur in concrete containing certain types of aggregate containing reactive forms of silica and cement in the concentrations required to produce such a reaction. The reaction is irreversible and may continue for many years in hardened concrete, although the intensity of the reaction generally declines with passage of time. Observable surface defects associated with the alkali-silica reaction include the well known fracture pattern, heaving, joint displacement, and spalling. Most test results conclude that the expansion of concrete in dams caused by alkali-silica reaction generally results in a retrogression of compressive strength and modulus of elasticity. The rate of reduction in quality is often rapid during the first period of years following construction, and then gradually declines until there is little reduction in strength after many years following construction.
Cavitation	Cavitation of concrete is the result of rapid movement of water or other liquids over the surface of the concrete.
Cracking (Concrete)	Cracking resulting from construction movement, settlement, shrinkage around reinforcement; setting due to inadequate finishing and curing; chemical reactions; physical reactions such as drying shrinkage; thermal changes; stress concentrations; structural design; accidents from overload, vibration, fatigue and earthquake. Inspection records should include the location and areal extent of any highly concentrated areas; a measurement of depth and width (range) of cracks; and an estimated cause of the cracking. A Level III inspection should be performed if a crack is greater than 6 inches deep or 1 inch wide to determine the cause of cracking and to evaluate the impact on the stability of the tunnel.
Cracking (Metal)	Structural cracking resulting in tearing, ripping or shearing of the material. Cracks can be random, horizontal, vertical or diagonal. Inspection records should include the location, length and open width of the crack and an estimate of the concentration of cracks.
Crazing	Surface shrinkage more rapid than interior of concrete mass, resulting from too high a slump; too rich a concrete mix; poor timing on the finishing; or too rapid absorption of moisture.

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Corrosion, Rust	The oxidation of a metal or other material by chemical or electrochemical action after prolonged exposure. Record the location, areal extent, and estimated depth of rusting. Replace rusted panel if unsightly or if necessary.
Damaged, Missing Sections	Broken, damaged, cracked or missing units or sections of tunnel liner. Inspection records should include the location and size of damaged or missing panels. Remove, repair or replace affected tunnel liner as necessary.
Delamination	Loosening or separation of laminar surface concrete.
Discontinuity (Rock)	A surface separating two unrelated groups of rocks. Any interruption in sedimentation, whatever its cause or length, usually a manifestation of non-deposition and accompanying erosion. The terminology can also include such fractures in rock as joints, bedding planes, shear zones, faults, and foliation.
Efflorescence	A whitish powdery deposit of soluble salts brought to the surface by moisture that leave residue after evaporating.
Exposed Reinforcement	Insufficient cover over steel reinforcing bars, resulting in exposure of the steel. This condition can result from insufficient concrete thickness over the steel reinforcing; the quality of the concrete; superficial deterioration of the concrete; or the overuse of calcium chloride as an admixture. Inspection records should include the location and areal extent of steel reinforcing exposure. Patch the deteriorated liner as necessary.
Form Scabbing	Scabbing of the concrete surface resulting from improperly applied form oil.
Foundation Wall Cracking	Stress or shear cracking, diagonal or step cracking resulting from slippage or movement of the footing. Inspection records should include the location, areal extent and concentration of cracking. A Level III inspection should be performed to identify the cause of the foundation cracking and to assess the stability of the tunnel. The cracks should be patched or unstable areas shored as necessary.
Holes	Holes resulting from chemical reaction or inadequate construction and design.
Impact Damage, Denting	Depressions, punctures, or buckled surface from objects striking or impacting the tunnel liner.
Improper, Insufficient Anchorage	Broken, damaged, loose, corroded, or missing anchorage or fasteners.

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Inadequate Expansion Joint	Lack of expansion or control joints resulting in surface cracking from stresses. If cracking is severe, the condition may warrant a Level III inspection to determine what remedial measures are available to control additional cracking.
Insufficient, Clogged Weepholes	Blocked or closed weepholes or improper number preventing drainage of trapped water. Inspection records should indicate the number and location of blocked weepholes. Clean out weepholes (routine maintenance) or construct new or additional weepholes.
Joints (Rock)	A surface of fracture or parting in a rock, without displacement; the surface is usually planar and often occurs with parallel joints to form part of a joint set. Jointing is the condition or presence of joints in a body of rock. Open joints at tunnel level can result in a passageway for seepage infiltration.
Joint Separation (Structural)	Separation of lap joints. Inspection records should include location, length and width of open joints. All joints should be filled with appropriate joint filler material.
Lateral Movement	Shifting caused by external forces such as hydrostatic pressure or ground movement. Inspection records should include location, areal extent, and estimated amount of lateral movement. A Level III inspection should be performed to determine the cause of the movement and to assess the impact of the movement on the stability of the tunnel. Perform remedial measures as necessary to brace the tunnel from further movement.
Loose Tile	Loose tile due to failing adhesive. Tile is generally attached to the surface of the tunnel liner through the use of an adhesive. Inspection records should include the location and areal extent of the loose tile, plus noting if the condition is associated with moisture related problems. Remove and replace loose tile with new adhesive backing if necessary.
Metal Fatigue	Loss of structural integrity and weakening of material from stress cracks, torquing, or bending. Inspection records should include the location and areal extent of damage. A Level III inspection should be performed to determine the cause of metal fatigue and any hidden extent. Damaged sections should be repaired or replaced as necessary.
Mortar, Joint Material Missing, Eroded	Deteriorated or damaged joint mortar which has fallen out or is loose or crumbly. Inspection records should include the location and a measurement of the areal or linear extent, whichever is appropriate, as well as the cause of the problem (i.e. seepage, physical contact, etc.). Patch or perform remedial measures to alleviate the problem prior to patching.

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Out-of-alignment	Bowing, deflection, or other movement that brings the surface of the tunnel out of plumb in one or more directions. The movement of the liner can be the result of stress development in the tunnel liner; disturbance of the materials (soil or rock) surrounding the liner; loss of material around the liner; or seepage or leakage into the tunnel. The location of the displacement should be noted (by station, roof or left or right wall, etc.) and the amount of displacement estimated. Displacements in excess of 1" should trigger a Level III inspection to determine the cause and to assess the impact of the displacement on tunnel stability. The Level III inspections may include advanced testing or inspection methods, or promote continued monitoring of existing conditions.
Plant growth, moss, algae	Plant life growth over the surface of the tunnel, usually resulting from excessive moisture in the tunnel. Inspection should include a review of adjacent areas for structural damage due to excessive moisture. Remove vegetation growth as part of routine maintenance.
Puncture, holes, tear	Holes, punctures, or tears in surface caused by missing fasteners, corrosion, or traffic. Inspection records should include location, areal extent, and identification of the cause of damage. Defects should be patched or repaired as necessary.
Rock Burst	A sudden and often violent breaking of a mass of rock from the walls of a tunnel, mine or deep quarry, caused by failure of highly stressed rock and the rapid or instantaneous release of accumulated strain energy. It may result in closure of a mine opening or projection of broken rock into it, accompanied by ground tremors, rockfalls, and air concussions.
Settlement (Concrete)	Sinking of solid particles in fresh concrete, after placement and before initial set.
Spalling	Flaking or scaling of tile or concrete caused by aging, weathering (freeze/thaw) and/or defective material. Inspection records should include location and areal extent of spalled tile. Replace spalled tile as necessary.
Staining	Surface discoloration from a foreign substance or material. Low level severity condition, not affecting the stability of the tunnel. Surface discoloration is frequently associated with seepage into the tunnel; exposure to weather (near portals); or exposure to smoke and exhaust from vehicular or rail traffic. Closer inspection may be required if staining is associated with seepage conditions.

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Surface Deterioration	Crazing, small surface cracks, or surface corrosion and breakdown due to weather, pressure, or other actions. Depending on degree of deterioration, further activities may include continued observation of conditions or replacement and/or repair as necessary as part of routine maintenance work.
Uneven Settlement	Improper compaction of backfill and weak or loose spots in grade causing sinking and slipping of the footing. Settlement is usually indicated by a grade change and wall or substructure movement. Inspection records should include location, areal extent, and estimated amount of settlement. A Level III inspection should be performed to determine the cause of the settlement and to assess the impact on the stability of the tunnel.
Uplift, Hydrostatic Pressure	Upward movement of footings from external pressures or hydrostatic pressure. Conditions are usually evident by slab movement or wall cracking with water or moisture penetration. A Level III inspection should be performed to assess the impact of the uplift pressure on the stability of the tunnel. Advanced tests or inspections may be required to determine the extent and/or level of pressure applied. Perform remedial measures to relieve uplift or hydrostatic pressure if necessary.
Weathering	Changes in color, texture, strength, chemical composition, or other properties of a natural (slate) or artificial (concrete) material due to age and weathering. Inspection records should include location and areal extent of the weathered zones and a description of the degree of weathering.
Weathering (Rock)	The mechanical or chemical breakdown of rock material due to exposure to various conditions over time.
- Slightly Weathered	Rock fresh, joints stained, discoloration extends into rock up to 1 inch. Joints may contain clay.
- Moderately Weathered	Significant portions of the rock show discoloration. Rock has dull sound under hammer.
- Severely Weathered	Rock "fabric" clear, but reduced in strength to soil. Some fragments of strong rock usually left.
- Completely Weathered	Rock reduced to soil. Rock fabric may be discernible. Quartz may be present as stringers.

APPENDIX C

LIFE CYCLE

17 TUNNEL STRUCTURE

17.01 TUNNEL STRUCTURE

Vehicular, Utility, or Railroad Tunnels	50 YRS

Note: It is not uncommon to find brick masonry linings in rail and waste water conveyance tunnels with service life longer than 50 to 100 years. Although many of these linings are in excellent condition, there are instances when they must be reevaluated.

Source:
Guidelines for Tunnel Lining Design, Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, American Society of Civil Engineers, 1984.

17.02 TUNNEL DRAINAGE

Gravity Flow System	50 YRS
Pumped System	50 YRS
Pumps	20 YRS

Source:
Guidelines for Tunnel Lining Design, Technical Committee on Tunnel Lining Design of the Underground Technology Research Council, American Society of Civil Engineers, 1984.

Inspection of Shore Facilities, NAVFAC MO-322, Volume II, January 1993.